Universitat
de les Illes Balears

DOCTORAL THESIS
2016

ANALYSIS AND RELATIONS BETWEEN ORGANIZATIONAL FACTORS, COMPANY PERFORMANCE AND RISK LEVEL ON SITE AT CONSTRUCTION SECTOR

Francisco José Forteza Oliver

DOCTORAL THESIS
2016

Doctoral Programme of Economics, Management and Organization

ANALYSIS AND RELATIONS BETWEEN ORGANIZATIONAL FACTORS, COMPANY PERFORMANCE AND RISK LEVEL ON SITE AT CONSTRUCTION SECTOR

Francisco José Forteza Oliver

Thesis Supervisor: José María Carretero Gómez
Thesis Supervisor: Alberto José Sesé Abad
Thesis tutor: Rafel Crespí Cladera

Doctor by the Universitat de les Illes Balears

Universitat de les Illes Balears

Dr José María Carretero Gómez and Dr. Alberto José Sesé Abad, of Universitat de les Illes Balears

WE DECLARE:

That the thesis titles *Analysis and relations between organizational factors, company performance and risk level on site at construction sector,* presented by Francisco José Forteza Oliver to obtain a doctoral degree, has been completed under our supervision.

For all intents and purposes, we hereby sign this document.

Signature

Palma de Mallorca, june 2016

To my wife, Sylvia, who is always here with her support, for this and other projects.

Acknowledgements

My utmost and most sincere gratitude to my thesis directors, Pepé and Albert for they continuous support, guidance, and unlimited patient. Without them, I would not have been able to achieve in this present challenge.

I would also like to express my gratitude to my tutor Rafel for his help and support in accessing the PhD program and to all the people responsible in Barcelona, Navarra and especially those here in Mallorca, with special mention to Lluis.

I also feel grateful to the people than help us to resolve doubts, especially Abel for the always unpleasant methodological aspects, and also to Mateo for helping with the excel programme pages to build the panel data.

My thanks also to the Committee because of the review and recommendations at the predefense, specially to Dr. Swuste for his detailed feedback.

I do not want to forget my research group colleagues for the mutual enthusiasm, for the support and the common barrier trying to get a PhD at our age.

Spanish Summary

El sector de la construcción tiene mala reputación en materia de seguridad y salud debido a sus altos índices de siniestralidad. La investigación actual dispone de métodos de evaluación de riegos cada vez más ajustados y gira hacia la búsqueda de indicadores adelantados (leading indicators), que ofrezcan señales del riesgo antes de que se manifieste. Son indicadores tales como el tamaño de la obra, los recursos y otros aspectos organizativos.

Una peculiaridad del sector es “la obra” como centro de trabajo único e irrepetible, cuyas especiales características afectan a la generación y evolución del riesgo. Sin embargo, las herramientas de evaluación disponibles no capturan estas especiales características de cada obra que pueden incidir sobre el riesgo. Se limitan a identificar y evaluar los riesgos, elegidos de entre una jerarquía de eventos predefinida. La unidad de análisis de estos modelos es el propio evento de riesgo.

En este contexto se ha introducido un nuevo concepto de “riesgo de la obra”, como el riesgo asociado a la totalidad de la obra, que es generado a partir de la consideración conjunta de diferentes elementos que individualmente afectan al riesgo. Al actuar conjuntamente, estos elementos producen sinergias potenciales que únicamente podemos capturar si utilizamos la obra como unidad de análisis.

Para capturar este riesgo de cada obra, proponemos un nuevo modelo evaluativo, CONSRAT, que tomando la obra como unidad de análisis, evalúa conjuntamente aspectos de la estructura organizativa y recursos, a la vez que las condiciones materiales y barreras. Este modelo se ha validado empíricamente.

La siguiente fase de investigación consiste en relacionar empíricamente condiciones de riesgo, con aspectos organizativos de estructura y recursos de la obra. El análisis se ha llevado a cabo mediante modelos de ecuaciones estructurales SEM (Structural Equation Modeling) en la que una serie de variables latentes de tipo organizativo, se han relacionado con los niveles de riesgo para cada obra. Las variables de campo se han obtenido utilizando la herramienta CONSRAT.

Los elementos organizativos, aunque definidos en la literatura, carecen en muchos casos de una justificación empírica de su relación con el riesgo. Por este motivo, nuestra investigación aporta nuevos hallazgos en la relación con estos aspectos. Los elementos organizativos más destacables en relación con los niveles de riesgo obtenidos son: Estructura y medios de las empresas, la asunción del control en obra mediante la efectiva presencia de los recursos necesarios y con las funciones preventivas adecuadas, el control del número de contratistas y el número total de empresas.

Por último, nuestra investigación se adentra en un campo con escasos estudios previos, y de nuevo con base empírica. Se trata de analizar la relación entre niveles de riesgo en la obra y tasas de accidente y entre tasas de accidente y los resultados económicos de las empresas. En este caso, la metodología utilizada es la construcción de un panel de datos (*panel data*) y el establecimiento de modelos de regresiones. El resultado más relevante es la obtención de evidencias empíricas de la existencia de una relación cuadrática entre accidentes y rendimiento económico, así como la obtención de la relación entre el nivel de

riesgo y tasas de accidentes. Los resultados empíricos obtenidos implican que es posible la simultaneidad entre incremento de tasas de accidente y beneficios de las empresas, lo que implica la necesidad de un mayor control y regulación por parte de la Administración, para alinear intereses privados e intereses sociales y evitar que pueda ser rentable para las empresas mantener ciertos niveles de accidentes socialmente no aceptables. Este mayor control se debería establecer con carácter previo a la manifestación del accidente y no a posteriori.

Acronyms

ALARP. As Low As Reasonably Practicable.
APP. Application (computers).
CHASTE. Construction Hazard Assessment with Spatial and Temporal Exposure.
CONSRAT. Constructions Sites Risk Assessment Tool.
CP. Collective Protections.
H&S. Health and Safety.
H&SP. Health and Safety Plan
H&SC. Health and Safety Coordinator.
HSE. Health and Safety Executive.
ORP. Occupational Risk Prevention.
OV. Organizational Variable.
PPE. Personal Protection Equipment.
QRAM. Qualitative Occupational Safety Risk Assessment Model.
RL. Risk Level.
ROA. Return of Assets.
RV. Risk Variable.
SEM. Structural Equation Model.
SME. Small and Medium Enterprises.
SP. Safety Performance.
SMI. Safety Management Index.
SP. Safety Performance.
SPI. Safety Performance Index.
SRI. Site Risk Index.
STATA. Data Analysis and Statistical Software.
TR. *Talonrakentaminen Riski*, Building construction risk.
VIF. Variance inflation factor.

Thesis modality.

Present PhD thesis is presented under the modality of compendium of articles. The three articles that conforms present thesis and the authors' references are listed below. All they have fulfilled the duties of the corresponding PhD program.

First article:

CONSRAT. Construction sites risk assessment tool.

Francisco J. Forteza, Doctoring

Albert Sesé, *PhD Department of Psychology, Balearic Islands University*

Jose M. Carretero-Gómez, *PhD Business Economics Department, Balearic Islands University*

Awarded as the best poster by the Scientific Committee of the XV International Conference on Occupational Risk Prevention (ORP). ORP was held in Santiago de Chile in November, 2015.

In review process on Safety Science journal.

Second article:

The impact of organizational complexity and resources on constructions sites risk.

Francisco J. Forteza, doctoring

Albert Sesé, *PhD Department of Psychology, Balearic Islands University*

Jose M. Carretero-Gómez, *PhD Business Economics Department, Balearic Islands University*

Third article:

Occupational risks, accidents on sites and economic performance of construction firms.

Francisco J. Forteza, doctoring

Albert Sesé, *PhD Department of Psychology, Balearic Islands University*

Jose M. Carretero-Gómez, *PhD Business Economics Department, Balearic Islands University*

Index

Abstract

Our research is focused on construction sector and the actual construction site as a specific work place. The site has specific characteristics that affect risk generation and its evolution. But, the presently available risk assessment tools do not capture all the possible specificities of construction sites that may affect risk, because they only focus on assessing risks from an already predefined hierarchy of events.

One of our main challenges is to design a tool that measure site risk, as the associated with the whole construction site, which is generated by uniting different elements which individually affect risk. By doing so, we introduce the new concept of “site risk” and a new risk assessment model, called Construction Site Risk Assessment Tool (CONSRAT), that takes the site as a unit of analysis and also includes material conditions, organizational structure and site resources.

Once having designed CONSRAT, we proposed to test our main hypothesis that relates site complexity and site organizational design complexity with the direct increasing effect on risk level. A Structural Equation Modelling (SEM) approach was adopted to obtain empirical evidences for testing our theoretical model.

To develop our empirical research, we visited and assessed 957 building sites in Spain. All the needed data was obtained by using our own tool specifically designed for this propose. CONSRAT operationalizes the variables to fit out the model, specifically, a site risk index (SRI) to measure the level of risk on sites and 10 organizational variables that we use to build four latent variables. Our most important contribution in this field is to show evidence that supports the hypothesis that some management issues matter on risk levels.

Our present research ends examining the relationships among level of risk conditions on construction sites, accident rates and economic performance of firms. In order to do that, we used a part of the main sites’ sample commented above, with the levels of risk on site obtained with CONSRAT. In this case, with those risk levels obtained, we have added the economic firm results and accident rates. With all this information we have built a panel data.

The general hypothesis in this section is that the level of risk on site has an effect on accident rates, and accident rates have an effect on economic firm performance. Our results show a statistically significant evidence of the relationship between the level of risk on site and accident rates. We have partially confirmed the next hypotheses about the quadratic influence between accidents rates and economic performance. This quadratic term confirms that there is a more complex relationship than lineal between those variables. This relationship gives us empirical evidence that, initially, it is possible to combine an increase in accidents with an increase of assets, but there is an inflection point where this tendency changes and more levels of accidents decrease the finally financial performance. Results are relevant to contribute to actual knowledge in this field because of two main reasons: first, considering the lack of research at task level on sites, the present research contributes to this important issue. Secondly, based on our empirical evidences, we concluded that it necessary more promotion and control by the Public Administration over the live conditions on site. This is because the companies, trying to maximize their economic results, may not

find the optimal level of accidents rate, understanding this optimal level by global terms. That includes social, personal and company interests.

Resumen

Nuestra investigación se centra en el sector de la construcción y en la obra de construcción como su emplazamiento de trabajo específico. La obra tiene características especiales que afectan a la generación y evolución del riesgo. Sin embargo, las herramientas disponibles para la evaluación del riesgo no capturan las especificidades de la obra que pueden afectar al riesgo, ello es debido a que éstas únicamente se centran en evaluar riesgos identificados procedentes de una jerarquía de eventos predefinida.

Una de nuestras metas más importantes es diseñar una herramienta que sea capaz de capturar el riesgo asociado a toda la obra en su conjunto, riesgo que es generado al tener conjuntamente diversos elementos que individualmente producen riesgo. Para conseguirlo, hemos definido un nuevo concepto de "riesgo de la obra" y un nuevo modelo de medición de este concepto, llamado Construction Site Risk Assessment Tool (CONSRAT), que toma la obra como unidad de análisis e incluye en el modelo tanto aspectos de las condiciones materiales de obra como aspectos de la estructura organizativa y recursos de la misma.

Una vez diseñada CONSRAT, hemos propuesto comprobar nuestra principal hipótesis que relaciona la complejidad de la obra y la complejidad del diseño de la organización con el incremento del nivel de riesgo de la misma. Se ha propuesto un modelo de ecuaciones estructurales (Structural Equation Model, SEM) para validar nuestro modelo teórico.

Para llevar a cabo nuestra investigación empírica, hemos visitado y evaluado 957 obras de edificación en España. Todos los datos se han obtenido utilizando nuestra específica herramienta diseñada para ello. Mediante CONSRAT construimos las variables para ajustar nuestro modelo, ello incluye un índice de riesgo de la obra (SRI), formado por nuestras variables de riesgo y las variables organizacionales que usamos para construir las variables latentes del modelo. Nuestra contribución más importante en este campo es mostrar evidencia que da soporte a la hipótesis de que algunos elementos de la gestión impactan sobre el nivel de riesgo.

Nuestra investigación finaliza examinando las relaciones entre las condiciones de nivel de riesgo en obra, las tasas de accidente y el desempeño económico de las empresas. Para hacerlo, hemos usado una parte de la muestra de obras comentada con anterioridad, con los niveles de riesgo obtenidos con CONSRAT. En este caso, a los niveles de riesgo obtenidos, hemos añadido los resultados económicos de la empresa y las tasas de accidentes. Con toda esta información hemos construido un panel de datos (panel data).

Las hipótesis generales en este apartado son que el nivel de riesgo en obra tiene un efecto sobre las tasas de accidente de las empresas y que las tasas de accidentes tienen un efecto sobre el rendimiento económico de las empresas. Como resultado de esta parte del estudio se ha obtenido una significativa evidencia de relación entre nivel de riesgo y tasa de accidentes. También hemos confirmado parcialmente nuestra siguiente hipótesis sobre la relación cuadrática entre tasas de accidentes y desempeño económico de la empresa. Esta evidencia en términos cuadráticos sugiere una mayor complejidad que la relación lineal entre estas variables. Esta relación nos da evidencia empírica de que, inicialmente, se puede simultanear un incremento de accidentes con un incremento de beneficios, pero hay un punto de inflexión que esta tendencia cambia y más tasas de accidentes finalmente

reducen el rendimiento económico. Los resultados son relevantes para contribuir sobre el actual conocimiento en este campo debido a dos motivos principales: primero, considerando la falta de investigaciones a nivel de las tareas en obra, la presente investigación contribuye a dar información directa en este campo concreto de la obra. En segundo lugar, en base a la evidencia empírica obtenida, concluimos que es necesaria más promoción y control por parte de la Administración Pública de las condiciones específicas a pie de obra. Ello es debido a que las empresas, tratando de maximizar sus resultados económicos, pueden no alcanzar un óptimo en la tasa de accidentes, entendido este nivel óptimo en términos globales, es decir tanto sociales, empresariales o personales.

Resum

La nostra recerca se centra en el sector de la construcció i en l’obra de construcció com l’emplaçament de treball específic. L’obra té característiques especials que afecten la generació i evolució del risc. No obstant això, les eines disponibles per a l’avaluació del risc no capturen les especificitats de l’obra que el poden afectar, i això és degut al fet que aquestes únicament se centren a avaluar riscs identificats procedents d’una jerarquia d’esdeveniments predefinida.

Una de les nostres fites més importants és dissenyar una eina que sigui capaç de capturar el risc associat a tota l’obra en conjunt, risc que es genera perquè es donen conjuntament diversos elements que hi incideixen individualment. Per aconseguir-ho, hem definit un nou concepte de «risc d’obra» i un nou model de mesurament amb aquest concepte, CONSRAT, que pren l’obra com a unitat d’anàlisi i inclou en el model tant aspectes de les condicions materials de l’obra com aspectes de l’estructura organitzativa i recursos d’aquesta.

Una vegada dissenyat CONSRAT, ens hem proposat comprovar la nostra principal hipòtesi, que relaciona la complexitat de l’obra i la complexitat del disseny organitzatiu amb l’increment del nivell de risc de l’obra. S’ha proposat un model d’equacions estructurals (Structural Equation Model, SEM) per tal de validar el nostre model teòric.

Per dur a terme la nostra investigació empírica, hem visitat i avaluat 957 obres d’edificació d’Espanya. Totes les dades s’han obtingut utilitzant la nostra eina específica dissenyada per a això. Mitjançant CONSRAT construïm les variables per ajustar el nostre model, i això inclou un índex de risc de l’obra (SRI), format per les nostres variables de risc i les variables organitzacionals que usem per construir les variables latents del model. La nostra contribució més important en aquest camp és mostrar l’evidència que dóna suport a la hipòtesi que hi ha elements de la gestió que impacten sobre el nivell de risc. Aquestes evidències tenen aplicacions pràctiques a l’hora de planificar i controlar la gestió a l’obra, ja que permeten introduir millors mitjans de gestió i proposar els elements de control més adients a peu d’obra.

La nostra investigació acaba examinant les relacions entre les condicions de nivell de risc a l’obra, les taxes d’accidents i el rèdit econòmic de les empreses. Per fer-ho, hem usat la mostra d’obres esmentada amb anterioritat amb els nivells de risc obtinguts amb CONSRAT. En aquest cas, als nivells de risc obtinguts hi hem afegit els resultats econòmics de l’empresa i les taxes d’accidents. Amb tota aquesta informació hem construït les dades de panel (panel data).

Les hipòtesis generals en aquest apartat són que el nivell de risc en obra té un efecte sobre el nivell d’accidents, mentre que el nivell d’accidents està relacionat amb el rendiment econòmic de l’empresa. Com a resultat d’aquesta part de l’estudi s’ha obtingut evidència significativa entre els nivells de risc a l’obra i les taxes d’accidents. També hem pogut confirmar parcialment la següent hipòtesi, i hem obtingut una relació quadràtica entre taxes d’accidents i rendiment econòmic de l’empresa. Aquesta evidència en termes quadràtics suggereix una complexitat més gran que la relació lineal entre aquestes variables. Aquesta relació ens dóna evidència empírica que inicialment és possible compaginar un increment d’accidents amb un increment de beneficis, però hi ha un punt d’inflexió en el qual aquesta

tendència canvia i resulta que si hi ha més taxes d'accidents finalment es redueix el rendiment econòmic.

Els resultats són rellevants perquè contribueixen al coneixement actual en aquest camp per dos motius principals: primer, considerant la falta d'investigacions al nivell de les feines a l'obra, la present investigació contribueix a donar-ne informació de camp directa; en segon lloc, basant-nos en l'evidència empírica obtinguda, concloem que són necessaris més promoció i control per part de l'Administració pública de les condicions específiques a peu d'obra. Això és degut al fet que les empreses, tractant de maximitzar els seus resultats econòmics, poden no arribar a un òptim en la taxa d'accidents, entenent aquest nivell òptim en termes globals, és a dir, tant socials com empresarials o personals.

Introduction

“Construction is different” because of the special characteristics of the construction process (Swuste et. al., 2012) which is located in special work places we name “construction sites”. The access is restricted, which explains that research on the subject is limited due to the lack of exposition measures (Swuste et. al., 2012). Studies at task level only represent the 2.28% of all available research (Zhou et. al,2015). Moreover, traditional assessment methods are not specific for construction (Pinto et. al., 2011) and they do not provide complete information including risk factors and the organizational structure of the site. More attention must be paid to determine the effects of organisational factors and their role in site safety performance (Swuste et al., 2016; Zhou et al., 2015).

In summary, it seems necessary to complement the current research with direct site information. This information must consider the identification of the construction site in terms of its live conditions and also taking into account site organisation characteristics and resources that may have an impact on safety.

Since Hoewijk (1988) connected structure, culture and processes, as mutually dependent and conforming workers behaviour, organisational issues have been identified as one side of the factors influencing the safety at work. This is especially applicable in the construction sector because it is also characterized for the special conditions of agents structure and business processes (Donaghy, 2009; HSE, 2009). Construction companies are similar to an organic structure that manifests itself in its processes (Swuste et. al., 2012) and the special place where these processes are deployed, the construction site. There is a certain consensus about the qualitative relevance of the relationships between organisational factors and safety performance, but it is not clear the quantitative intensity of these relationships. There are very few empirical researches on literature about this question (Swuste et al., 2016). A low number of field research, specifically on construction sites, have connected and concreted these relationships (Teo & Ling, 2006; Fang et. al., 2004; Mohamed, 1999; Wu et. al., 2015) and even fewer researches have linked organisational and complexity with risk level assessed on site (D. P. Fang, Huang, et al., 2004).

Another stream of current research uses accidents to attempt to explain the relationships with risk identifications or accident factors characterization (Camino López et. al., 2011; Cheng et. al., 2012; Cheng et. al., 2010; Conte et. al., 2011). But, it is not so common to assess the risk conditions on site and to try to develop a related rule with accident rates. Moreover H&S has been identified as one of the issues that are relevant for company results and competitive advantage (Teo & Ling, 2006; Argilés-Bosch et al., 2014; Rechenthin, 2004). But there is a low appreciation for managers about the economic consequences of unsafe practices in the workplace (Harshbarger, 2001). The costs of accidents is the other side of the problem. There are a lot of factors related to accidents that affect costs: healthcare costs, lost production, delays, loss of working days, penalties, etc., for the individual, the company or government costs (HSE, 2015), but empirical research in this field is limited.

Objectives

The main objectives of our research are summarized in the following points:

- To propose and validate a new way for site risk assessment capable of capturing the construction site risk.
- To use this new method empirically to asses our construction site sample obtaining risk and organizational variables.
- To build a model in order to study the relationships between organizational issues and risk levels on site, and estimate them empirically.
- To analyse and empirically estimate the complex relationships between risk level on accident rates and accidents rates on firm financial performance.

1. - CONSRAT. Construction sites risk assessment tool.

1.1. - Abstract

One peculiarity of the construction sector is that each construction site represents a unique workplace. The specific characteristics of the site affect risk generation and its evolution. However, available risk assessment tools do not capture the specificities of construction sites that may affect risk, because they only focus on assessing identified risks from a predefined hierarchy of events. This paper proposes a new "site risk" concept that is defined as the risk associated to the whole construction site that is generated by having together different elements which individually affect risk. Potential risk synergies may exist and they only can be captured adopting the construction site as unit of analysis. In doing so, a new Construction Site Risk Assessment Tool (CONSRAT) is presented. This is done considering also both organizational structure and resources jointly with material conditions. The tool was used to assess 150 construction sites in order to obtain convergent and internal validity evidences. Another validated tool was used as external criterion: the Qualitative occupational safety Risk Assessment Model (QRAM). Results provide adequate validity evidences for both the internal structure and the expected relationships with the external criterion. CONSRAT design and complete instructions for its use are described. As a unique contribution, CONSRAT adopts a new site risk approach to assess the main live conditions, complexity factors and organizational structure characteristics which are related to construction site risk.

Keywords: Construction sector, Safety Risk Assessment, Site Risk, Organizational conditions.

1.2. - Introduction

Construction sites represent a workplace with limited access for research purposes, which means the lack of exposure measures (Swuste et al., 2012). Swuste et al. (2012) pointed out that "construction is different", due to these special characteristics of the construction process. In fact, studies at task level only represent the 2.28% of all available research, that makes necessary to drive more attention to safe construction task (Zhou et al., 2015).

Research based on accidents rates mainly focuses on the accidents related tasks or risks (Conte et al., 2011), or the size of the company (McVittie et al., 1997), or the accident hierarchy to risk assessments (Pinto, 2014; Swuste et al., 2012). Other studies have included personal characteristics and interpersonal and organizational variables that may be implicated in the occurrence of work-related accidents by means of self-reported measurements or accident modeling (Bellamy et al., 2008; Sesé, 2003; Tomas, Melia, & Oliver, 1999). All these approaches generally implement in a correct way an ex post facto design, but they have limited information on the contexts where the accidents occurred. Safety cannot be improved by only looking to the past and taking measurements against the occurred accidents, because this information is so specific and distinctive for each accident, that it becomes difficult to develop knowledge with enough generality (Hollnagel, 2008). Analyse scenarios of accidents obtaining their information is valuable but it may be broadened. Different initiatives have studied deeper occupational accidents as the Occupation risk model (ORM) developed by the Dutch Workgroup Occupational Risk Model (WORM), or the Danish safety method (Jørgensen, 2011). WORM model provided several lists of major scenarios of accidents per industrial sector. Large studies are developing using the data from this model, for example, Ale et al. (2008) develop an ORM to quantifying occupational risks that analyses scenarios to link cause with consequences. Jørgensen et al. (2010) adapts ORM model form SME in Danish context. Bellamy (2015) studied the relationships between hazards, fatal and non-fatal accidents concluding that is necessary a deeper examination of hazards and their barriers. Finally, Aneziris et al. (2008) quantified risk assessment for fall from height. Other current research complement these lines is working on precursor analysis field, near misses or leading indicators capable to anticipate the accident obtaining predictors (Cambraia et al., 2010; Chi et al., 2012; Grabowski et al., 2007; J. Hinze et al., 2013; Memarian & Mitropoulos, 2013; Rozenfeld et al., 2010; Toellner, 2001; Wu et al., 2010; Yang et al., 2012).

It is important to note that the quality of obtained evidences strongly depends on the accuracy of applied assessment methods. Pinto et al. (2011) pointed out that general safety risk assessment methods are not specific for construction. Some instruments for assessing specific construction risks have been developed. One example is the Qualitative Occupational Safety Risk Assessment Model (QRAM) that incorporates uncertainty using fuzzy set (Pinto, 2014). QRAM analyses up to nine types of accidents, taking into account the effectiveness of the protections and the possibility and severity of risks. Risk assessment includes the dimension of organisational safety climate and the workplace safety level. In turn, the CHASTE method (Construction Hazard Assessment with Spatial and Temporal Exposure) tries to estimate the quantitative value of probability risk before accident occurs, by loss-of-control event (Rozenfeld et al., 2010). Other example is the TR index (*Talonrakentaminen Riski*, Building construction risk in Finnish) (Laitinen et al., 1999) that takes into account main items on building sites, calculated as a percentage of the 'correct' items related to all the observed items. This method could be useful as a means of objective feedback for the companies (Laitinen & Päivärinta, 2010; Laitinen, et al., 1999). These methods are conclusive on risk levels by means of different methodologies: QRAM, comparing with others validated models and expert opinion; CHASTE, applying the method to 14 activities, expert workshop and interviews with site engineers; and finally TR index was validated though correlations between its TR index and accidents rates of sites grouped according TR index. Looking at the other mentioned line of research, WORME project, and specifically its application on construction industry, the data required for risk quantification of workers at the "Storyborder" (the tool used to classify and analyse accidents) are the following: job position, activities of each worker, hazards for each activity and exposure to each hazard (Aneziris et al., 2010).

These tools use well-structured techniques to specify risk levels and focus on the pursuit of accuracy over traditional risk assessment. But these methods limit the possibility of analysing all elements that make up the construction site affecting risk. Elements such as complexity, size, human resources, internal organization, Health and Safety (H&S) plan, access, circulation, process, machinery, among others, are not specifically valued at most of them and are related with the major accidents as it is recover at some taxonomies (Bellamy et al., 2008; Niskanen et al., 2016). The main drawbacks lie in the relative complexity of its application at the construction site as a control tool, as well as its limitations to comprise the analysis of the general conditions and also the specific conditions of the construction site stage. For example, TR index does not systematise other conditions regarding the construction site structure or its environment. In other case as at WORM model, it is necessary a relative long period of time to assess the site, while our goal is obtain a fixed site assessment. In addition, these tools do not contemplate structure resources or other elements of site's organization to complete the analysis. In this sense, construction companies are similar to an organic structure that manifests itself in its processes (Swuste et al., 2012). Although processes may determine the organizational structure on site, the main contractor's resources seem to be determinant to assure the adequate amount of resources on site. The quantitative relationship between company scale and construction safety on site is still a gap at current research. More attention must be paid to determine the effects of organisational factors and their role in site safety (Swuste et al., 2016; Zhou et al., 2015). Specially, we stress the following four ones classified from literature: Site complexity that includes project complexity, site restrictions and level of construction or size of site (Fang et al., 2004; Hatipkarasulu, 2010; Hon et al., 2010; Manu, Ankrah et al., 2013); Organizational structure resources that includes size of firms, type of promoter or contractor and their involvement, or foreman authority (Camino et al., 2008; Cheng et al., 2010; Hallowell, 2011; Hallowell & Gambatese, 2009, 2010; Holte et al., 2015; Liao & Perng, 2008; Pérez-Alonso et al., 2011; Zou et al., 2010); Complexity of organizational design that refers to site internal structure and includes number of companies and their organization, the subcontracting levels and number of workers (Hallowell & Gambatese, 2009, 2010; Hinze, Hallowell, et al., 2013; Hinze, Thurman, et al., 2013; Liu et al., 2013; López-Alonso et al., 2013; Manu et al., 2013; Swuste et al., 2012; Yung, 2009); finally, Safety management resources that is referring to the preventive functions of the persons in charge and the existence of safety supervisors (Abudayyeh et al., 2006; Baxendale & Jones, 2000; Hallowell, 2011; Hallowell & Gambatese, 2009, 2010; Hinze, Hallowell, et al., 2013; Jarvis & Tint, 2009; Liu et al., 2013; Manu et al., 2013).

Beyond solving these tools' limitations, and taking into account the impact of organizational element on risk, it seems necessary a new approach based on the construction site risk analysis instead of restrict to obtain a measurement of each accident events from a hierarchy (Pinto, 2014; Swuste et al., 2012). In this way, this new approach means connect most of the physical elements related with site risk and its organizational structure. We refer to site elements that contain live conditions able to generate risk such as general site conditions (e.g. site access, circulations, order or collective protections), and main stage tasks conditions (e.g. access, falls or other risks, work process analysis and the collective and personal protections used on this main stage, auxiliary resources and machinery). All them taking in account useful items for our specific goal as job positions, type of activities, risk identification (Aneziris et al., 2010; Bellamy, 2009; Bellamy et al., 2008). Other important elements to consider are organisational characteristics such as complexity, size, resources, internal organization or preventive resources, among others.

In order to achieve this challenge, we introduce the concept of "site risk", which comprises the associated risk to the whole construction site that is generated by having together those different elements that individually generates risk. The aim of this study is to design and validate a new tool for assessing the site risk: CONstruction Site Risk Assessment Tool (CONSRAT). This instrument tries to meet the lack of tools for analysing the construction site as unit of analysis, with own identity and a structure which are different from the companies that compose the site.

1.3. - Methods

1.3.1. - Procedure

CONSRAT is built taken into account actual literature knowledge and personal technical experience of authors about H&S on construction sites. ScienceDirect database has mainly used for doing the literature review in the period 2011-2014. Firstly the search was focused on tools oriented to assess construction site risks, using as keywords: safety construction, construction risk assessment, construction site risk, construction resources, construction organization, and construction structure. Finally, the search was extended to more general terms as accident construction. A total number of 1864 studies were found and a final number of 135 that had direct relationship or implications to our study. Then we focus on tools that were specifically designed for risk site assessment. Literature review results about construction tools showed both a limited knowledge circumscribed to focus on individual construction risks, and the lack of methods focusing on site risk.

Previous knowledge focused on sites (Laitinen et al., 1999; Laitinen & Päivärinta, 2010; Pinto, 2014; Rozenfeld et al., 2010), general knowledge of Occupational Safety Risk Assessment (OSRA) and organizational elements, and all our technical background on safety construction were used to develop CONSRAT. In addition, a panel of 11 construction safety experts was consulted to obtain content validity evidences about our classification and variables composition. Finally, a sample of 150 sites was assessed with CONSRAT and QRAM methods in order to obtain both internal and convergent validity evidences.

1.3.2. - Sample

In order to address the empirical validation of CONSRAT, a randomly extracted sample of 150 construction sites with diverse typologies, construction phases and sizes was used. All sites have building construction typologies; the highest percentage corresponds to new construction (88%), completed by reforms and extensions (12%). The sample has similar proportions of single and multi-family housing (48% and 45% respectively, and 7% other uses). Most of the sites are from one to two floors (57%, height from 3 to 9 meters.); in second place we have buildings from three to five floors (38%, height from 9 to 18 meters).

Related to site organizational resources, we can underline that promoters are mostly professional companies (55%), followed by private individual (30%), and the rest of Public Administration (15%). The most of contractors are companies with different legal forms (96%), followed by any of the self-employed configuration (with or without workers, 4%). Most of the sites have one contractor (85%), and more than one firm (67%) working simultaneously on site. Sites with subcontracting represent the majority of the cases in our sample (62%). The mean number of workers in the sites of our sample is 14. Most of sites have site foreman (47%), followed by nobody in charge (23%) and single worker in charge (20%). In the majority of our sites there is not documented H&S plan (57%).

About site general information, the most common work stages is flat structure works (34%) and brickwork (24%), followed by facade works (20%) and roofs (18%). Most of the cases we have one main work (58%) and the workers are located on perimeters of floors or roofs (58%), followed by, interior floor (18%), and outdoor on auxiliary resources (15%).

1.3.3. - Instruments

The Qualitative Occupational Safety Risk Assessment Model QRAM (Pinto, 2014) was used as external criterion to CONSRAT for obtaining convergent validity evidences. QRAM is a tool designed to the construction industry and proposes a procedure for the estimation of risks at work, through a structured list of questions and their further processing to carry out the evaluation. The tool analyses up to nine types of accidents, taking into account the effectiveness of the protections and climate, using of fuzzy sets theory to improve the use of imprecise information. The final outcome of this tool shows several types of Risk Levels (RL). It was validated by a panel of experts and convergence validity evidences with other tools were also obtained. QRAM uses the ALARP (As Low a level As Reasonably Practicable) criteria to ranking the risks. Above ALARP levels, it considers the unacceptable level, below the acceptable, and between them, the ALARP area that means to practice a continuous improvement of safety conditions.

1.3.4. - Statistical analyses

Convergent and internal validity evidences were obtained by correlational analysis. Two correlation matrices were estimated, one between CONSRAT's risk and organizational variables, and another one between all CONSRAT variables and QRAM Risk Levels indicators (RL). Statistical assumptions for linear correlation were tested. Correlation matrices were estimated with SPSS 21.0 software (SPSS IBM Corp. Released, 2012).

1.4. - Results

1.4.1. - CONSRAT, the tool

The tool is structured in three parts: the form to be completed on field work on site by a technician (Appendix A-1), and the composition and weights to build 10 organizational, and 10 risk variables (Paragraph 2.4 and 2.5, appendices B-1 and C-1). The tool includes only a significant group of variables that are representative of the requirements of the proposed definition of site risk, while the type of sites is unlimited and consequently, the corresponding elements to be evaluated. CONSRAT form includes two broad parts of indicators (I and II) and two different valuation criteria. The first part refers to general information, organizational and resources factors on site. The second part, mainly evaluative of works conditions, is divided into four sections to determine the current risk conditions on site. The valuation criterion specifies the meaning of each level to be assessed and is developed at next section (2.2).

The tool cannot be considered as a classical risk assessment tool, if not a site risk assessment. For this reason, it does not include assessment of each individual risk. But it includes expressly fall from height risk as one on his variables, because the general prevalence of this risk (Ale et al., 2008; Aneziris et al., 2008) and the specific prevalence in construction sector (López et al., 2011; López et al., 2008; Swuste et al., 2012). The general scheme of the tool structure, indicating for each section their corresponding items according to Appendix A-1 is:

I. General information and organizational factors:
   i. Identification data: items 1 to 4
   ii. Construction site characterisation: items 5 to 9
      a. Stage of the works. Locations: items 10 to 13
   iii. Promoter characterisation: items 14 to 19
   iv. Constructor characterisation: items 20 to 30
   v. H&S Plan adequacy: items 31 to 32

II. Risk factors on site:
   i. H&S Plan compliance: item 33
   ii. General conditions valuation: items 34 to 38
   iii. Stage conditions valuation: 59 items
      a. Access: item 39
      b. Fall from a height: items 40 to 45
      c. Other risks concurrence: items 46 to 57
      d. Process valuation: items 58 to 60
      e. Collective protections: items 61 to 70
      f. Personal protection equipment: items 71 to 74
   iv. Auxiliary resources and machinery: 22 items
      a. Auxiliary resources: items 75 to 85
      b. Elevation resources: items 86 to 92
      c. Other machinery: items 93 to 97

1.4.1.1. - Levels of valuation

The existing indices that measure safety conditions in construction sites use several different scales. The most simple of all of them uses a dichotomy format: correct/ incorrect, such as for example in the TR index (Laitinen et al., 1999). This index was formerly used in combination with other factors and weights, such as safety plans, criteria changes at construction sites and company accident rates, in order to follow safety campaigns (Laitinen & Päivärinta, 2010). Other studies also use polytomous variables, such as for example the CHASTE method with four levels (Rozenfeld et al., 2010). Finally, in other cases, five or more levels are used (Hollnagel, 2008; Pinto, 2014; Rubio-Romero et al., 2013).

CONSRAT combines different scales for answering the different indicators. In general, a four level scale with zero corresponding to a full accomplishment level and three meaning very deficient or non-existent accomplishment level was used. A value ranging from 0.00 through 1.00 with equivalent increments of 0.33 is assigned to each level. In other cases a dichotomous scale is applied to value presence/absence or valuing the adequacy of protections. Specific scales used to each item are included in the form (Appendix A-1). Valuation criterion is also at Appendix A-1, at the end of the form.

The use of those four levels is justified by having a broad enough scale to avoid too wide valuations, but at the same time precise enough to prevent the result of the evaluation from falling in ambiguous zones with labels such as medium, partial or just fair accomplishment. With that kind of scale would be unclear what the final result of the evaluation might be. The final goal is to know whether or not the site that has been assessed is acceptable or not. In summary, it is a bipolar scale without a neutral point (favourable, 0 and 1, or unfavourable 2 and 3).

1.4.1.2. - Field work fulfilment

CONSRAT registers responses and assessments to a total of 97 items (using the questionnaire and criteria of Appendix A-1) and entails a four step process:

Step 1: Filling in the assessment template and rating (Appendix A-1). In doing so, we use the form and valuating with criteria that appears at the end. This step begins with an interview to the person in charge of site, the checking of the documentation that must be on site and filling the data required in the form. We have to ask to the foreman all items that we do not deduce just checking the site or documentation (i.e. type of contracting, number of workers or companies, subcontracting, etc.). It is important to check H&S plan, explicitly its previsions for actual work stage to be able to assess its actual compliance. Then, we begin a general visit to the construction work to assess its general elements. It is mainly outside and affecting the areas commonly used by all workers to access, located equipment and stockpile. For each element, and follow the form we just select the corresponding level according to the valuations criteria (four or two levels depending of each item). Then, we go into the building and assess its general collective protections without arriving to main stage. If we have several protections (several types, levels, etc.) we will always choose the worse. After that, going on to main stage, we will check its access. Finally, arriving to the main stage location and with similar criteria, we have to evaluate its specific conditions going on with the form items. Some items may need make questions to the foreman or workers, as the continuation of exposure and process (items 42 and 59), and observe an enough work time sequence.

Step 2: Items scoring. Items are direct, using mentioned valuation criteria at the end of the form. For each rating corresponds a scoring. As we have seen at paragraph 2.2 we have two different levels, general valuation with four and dichotomous valuation. This reduced criterion is used for items that do not need more clarification (i.e. adjustment to the phase, needed of more, risk identification).

Step 3: Levels of variables estimation. Final variable levels are estimated using the aggregate rules on Appendix B-1 and Appendix C-1 for organizational variables and risk variables respectively.

1.4.1.3. - Organizational variables

According to literature review and an expert panel content validity process, a total of ten organisational variables were considered. Table 1 shows the composition of each variable and the main literature references.

Table 1. Organizational variables, composition, CONSRAT and main literature references

Variable	Item	CONSRAT references[1]	Literature references
OV1. Complexity of project	- New construction site or reform and extensions - Building Configuration - Special environment conditions	5 6 18	(Fang, Huang, et al., 2004; Hon et al., 2010; Manu et al., 2010)
OV2. Size of site	- Number of floors	7	(Hatipkarasulu,2010; HSE, 2009)
OV3. Stage characteristics	- Main work stage - Secondary work stage	10 11	(Manu et al., 2010)
OV4. Promoter resources	- Type of promoter	14	(Behm, 2005; Hinze et al., 2013; Liu et al., 2013; Wu et al., 2015; Xinyu & Hinze, 2006)

OV5. Constructor resources	- Type of constructor - Constructor's Role - Site management structure	20 21 28	(Cheng el al., 2010; Camino López et al., 2011; Hallowell & Gambatese, 2009, 2010; Holte et al., 2015; Liao & Perng, 2008)
OV6. Internal organization structure	- Type of contracting - Number of companies at site - Level of subcontracting - Number of woks	17 22 24 12	(Hallowell, 2011; Hallowell & Gambatese, 2009, 2010; Hinze, Hallowell, et al., 2013; Hinze, Thurman, et al., 2013; Liu et al., 2013; López-Alonso et al., 2013; Manu et al., 2013; Swuste et al., 2012; Yung, 2009)
OV7. Job planning and design	- Employee location assignments - Total number of workers on site - Ratio of number of workers of principal constructor over total workers at site	13 27 26/27	(Fang, Huang, et al., 2004; López-Alonso et al., 2013; Manu et al., 2010)
OV8. Coordination resources	- Designation H&S coordinator - Documented work of H&S coordinator	15 16	(Fang, Huang, et al., 2004; Ros et al., 2013)
OV9. Preventive functions	- Preventive functions of the structure	29	(Baxendale & Jones, 2000; Hallowell, 2011; Hallowell & Gambatese, 2009, 2010; Hinze, Hallowell, et al., 2013; Jarvis & Tint, 2009; Liu et al., 2013; Mahmoudi et al., 2014; Manu et al., 2013)
OV10. H&S plan adequacy	- Presence at site of H&S Plan - Appropriateness of H&S plan's previsions	31 32	(Fang, Huang, et al., 2004; Hallowell, 2011; Hallowell & Gambatese, 2009, 2010; Hinze et al., 2013; Ros et al., 2013)

[1]See appendix A-1 for further information

Relating the literature on safety risk management with our tool, it can be seen that CONSRAT only includes two of the most mentioned safety program elements: "safety manager on site", and "written and comprehensive safety and health plan" (Hallowell, 2011; Hallowell & Gambatese, 2009, 2010; Hinze et al., 2013). As these authors claim, safety inspections are an element of safety management. Thus, although our tool might be considered as one more element of a safety risk management system, we do not propose it as a valid tool to evaluate the safety risk management system. We have considered in CONSRAT only those safety management elements that a technician can objectively verify on a single visit on site. We have avoided other elements which are based on perceptions (e.g. "upper management support", "employee involvement", etc.). Additionally, we have not incorporated other elements that need specific and more complex tools, including surveys, to obtain them (e.g. "subcontractor selection and management", "substance abuse programs", "safety and health committees", etc.).

In order to obtain content validity evidences for the classification of variables in Table1, a panel of 11 experts was carried out. All participants were experts with more than 15 years of experience on the field of construction. Some of them have professional experience as projectors and/or directors of several buildings constructions assuming safety and health functions. Five of them, in addition, have academic experience training in architecture or engineering subjects, including specific training on safety and health subjects. They were asked to classify all the 22 different items listed in Table 1 into one of the ten variables mentioned above. They were not forced to assign all the items to a given factor, i.e., they were allowed to not classify any of them if they thought there was no logical, technical or theoretical reason to do so. The result was that the experts correctly assigned all the given items, and consequently their associated item, to the variable previously considered by us, except in two items. The two non-concordant items were "Type of promoter" and "Number of works". In both cases, the a priori classification was changed maintaining the one supported by the panel of experts. The resulting final classification of each item/variable was supported by an average of 78.73% of the experts (*SD*= 12.89).

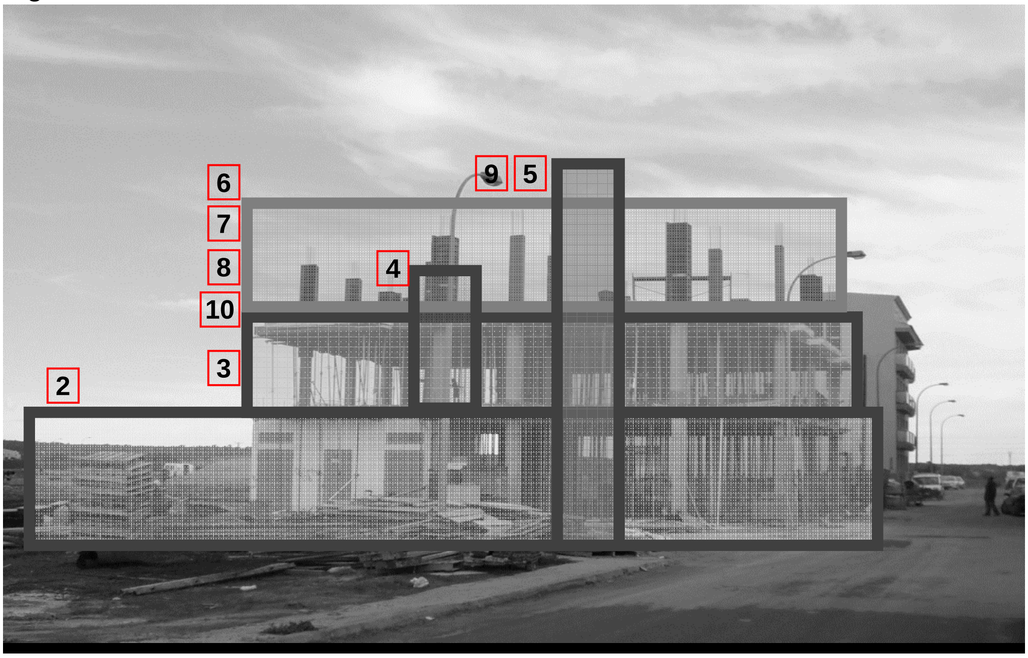
Appendix B-1 contains a summary of the rating scales, the scoring procedure used for measuring all items, and the aggregation rules to build organizational variables. The different metrics and scales used for item measurement reflect an increasing pattern in the level of either complexity or resources regarding that item. Thus, in all cases a higher observed value implies more complexity or more level of resources. In order to have all the different items measured in a common scale, the original observed values were transformed into percentiles according to its own range of measurement scale. With those values for each item the value of each organizational variable as the average of observed values in percentiles of its corresponding items was calculated. In this case complexity and resources do not have a specific classification like one will see at risk variables. The levels go from 0.00 to 1.00 that means from less to more levels on complexity and resources.

1.4.1.4. - Risk variables

CONSRAT holds a risk variables structure concerning the material conditions on site which is close to the organization of a building construction and compatible with the different parts of the site. In this sense, the variables try to reflect the organic structure of the site mentioned by Swuste et al. (2012), giving us on the one side general information of the site, and on the other side, specific information of the scenarios, which impact the overall valuation of a construction site. The aim of these risk variables is not provide all possible information of site. By contrast, our challenge is to build a structure to provide enough site information to propose adequate interventions fitted to the site, stage ejection and resources.

Figure 1 shows the location of each risk variable on site, trying to cover all its different sections. As each section is not a "closed box" and each site has its own characteristics, intersections are plausible, but focusing each variable it is possible to obtain information from whole site. A number of 10 risk variables are chosen not as a close and exhaustive number, but a selection of 10 important ones capable to define the site risk. Moreover, the point is not trying to assess each single risk, but site risk. In doing so, we consider individually one single risk (falls from height) because its prevalence and representative of our site risk level, according to obtained evidences. Other risks could be present or not, and they are grouping together in other variable. Other risk variables represent barriers or other issues connecting with risk.

Figure 1.- CONSRAT risk variables from site sections.



The composition of risk variables can be seen at Table 2 (scoring and aggregation rules are in Appendix C-1). Five of them are considered alarm variables (identified with an asterisk), i.e., they provide information about severe problems that need to be prioritised. Next each risk variable is explained in more detail:

H&S plan compliance (RV1). According to EU Directives, it is the main legal reference of H&S previsions that must be followed on site. This variable focusses on site stage. *General conditions of site (RV2)*. This variable is referred to common areas of site, without looking at the current stage. This is one of the variables that the available tools do not consider explicitly. We consider important to disaggregate this information. *General conditions of the collective protections (RV3)*. These conditions do not consider the current stage. It is needed to know the level of each collective protection on site (general and main stage) because they may require special treatment and actions. *Access* (*RV4*). It refers to the specific conditions of stage access, as a separate matter from those valued in the general conditions, because stage access frequently presents a different performance. *Falls from height* (*RV5*). This variable is the unique that includes a risk assessment and exclusively is composed by just this risk. This is because it is the most important risk on construction sites, always present at building construction and located at the top of risk on literature. It is measured at the current stage. We add, to the classical probability and severity items, four news items to improve the risk assessment with the specific site conditions. These items aggregate information for determining the needed intervention priorities.

Table 2. Risk variables and their composition with CONSRAT references

Variable	Item	CONSRAT Ref.[1]
RV1. H&S plan*	- Compliance	33
RV2. General conditions	- Construction fence	34
	- Circulations, order, tidiness, illuminations	35
	- Safety signage	36
	- Safety of electrical installation	37
RV3. Collective protections*	- General collective protections	38

RV4. Access	- Access to main work stage	39
RV5. Falls of height*	- Height of fall - Level of failure - Exposure continuation - Probability - Severity - Intervention required	40 41 42 43 44 45
RV6. Other risks	- Identification of 11 more risks - Incidence with Falls of height	46-56 57
RV7. Process	- Adequacy - Process deviation	59 60
RV8. Collectives protections*	- Scaffolds. Adjustment to the phase and installation validation (Ad. & Val.) - Safety nets. - Railing. - Safety boarded. validation - Necessity more Collective Protections	61-62 63-64 65-66 67-68 70
RV9. Personal protections*	- Fall protection system - Need for more PPE	71-72 74
RV10. Auxiliary resources and machinery	- Scaffolds (Ad. & Val.) - Suspended scaffolds. (Ad. & Val.) - Horse scaffolds. (Ad. & Val.) - Portable ladders. (Ad. & Val.) - Others. (Ad. & Val.) - Lift truck. (Ad. & Val.) - Crane truck. (Ad. & Val.) - Fall protection for elevation resources. (Ad. & Val.) - Auxiliary resources for elevation system. (Ad. & Val.) - Concrete mixer. (Ad. & Val.) - Manual tool. (Ad. & Val.)	75-76 77-78 79-80 81-82 83-84 86-87 88-89 90 91 93-94 95-96

* Alarm variables. [1]See appendix A-1 for further information

Other risks (*RV6*). This variable identifies the coincidence of 11 risks at the current stage, and their influence on the risk of falls from height. With this variable we want to estimate the effect of having together these risks and their effect on falls from height. We consider all these risks grouped together in one single variable, because in building construction are secondary in relation with fall height risk. *Process* (*RV7*). It identifies whether or not the works sequence is adequate and it is performed according to the planned process. It tries to cover the need to undertake a task analysis as the literature has been claimed. *Collective protections* (*RV8*). It evaluates these protections at the current stage. It is composed by the adequacy, the assessment of the installation, and the need for more collective protections. *Personal protections* (*RV9*). It evaluates personal falling from height protection at tasks execution. It is composed, measured and valued with the same criteria than *RV8. Auxiliary resources and machinery* (*RV10*). This variable evaluates the adequacy to the phase and an assessment of the installation of different resources and machinery. It is composed of twenty items including auxiliary resources and construction machinery, elevation machinery and other machinery.

CONSRAT risk variables are measured within a zero-one interval. We then classify the observed value of each risk variable into three groups: Correct (from 0 to 0.33 included), acceptable (above 0.33 and below 0.66) and unacceptable (from 0.66 to 1.00). Valuation criterion (Appendix A-1) explains the rules to choose the different levels. The main criteria to choose between acceptable and unacceptable, the critical step, must bases in legal normative application. When it is not clear or insufficient, it must be rating according train technician criteria taking in account the elements that appear in mentioned valuation criteria.

1.4.2. - CONSRAT validity evidences

1.4.2.1. – Relationships among CONSRAT variables

In order to address the empirical validation issue of CONSRAT, we have done an exploratory analysis of expected correlations. On first place, we have calculated the correlations among CONSRAT variables within.

Table 3.- Correlation matrix among CONSRAT variables

	RV1	RV2	RV3	RV4	RV5	RV6	RV7	RV8	RV9	RV10	OV1	OV2	OV3	OV4	OV5	OV6	OV7	OV8	OV9	OV10
RV1	1																			
RV2	,49**	1																		
RV3	,58**	,71**	1																	
RV4	,42**	,68**	,55**	1																
RV5	,69**	,64**	,71**	,59**	1															
RV6	,38**	,36**	,35**	,35**	,55**	1														
RV7	,66**	,65**	,73**	,58**	,83**	,56**	1													
RV8	,38**	,46**	,55**	,31**	,60**	,39**	,52**	1												
RV9	,46**	,45**	,64**	,34**	,66**	,31**	,61**	,47**	1											
RV10	,28**	,29**	,33**	,27**	,33**	,29**	,34**	,17*	,31**	1										
OV1	-,47**	-,35**	-,34**	-,29**	-,31**	-,06	-,42**	-,24**	-,12	-,15	1									
OV2	-,06	-,40**	-,35**	-,31**	,05	,17*	-,11	-,03	-,20*	-,13	,41**	1								
OV3	,39**	,24**	,36**	,23**	,39**	,25**	,53**	,17*	,40**	,31**	-,12	,07	1							
OV4	-,36**	-,41**	-,23**	-,22**	-,10	-,12	-,15	-,06	-,01	-,16	,43**	,38**	,16	1						
OV5	-,26**	-,20*	-,33**	-,13	-,05	,15	-,12	-,04	-,06	-,01	,27**	,37**	,08	,46**	1					
OV6	-,22**	-,20*	-,18*	,05	-,01	,03	-,04	,03	,01	,07	,07	,19*	,17*	,40**	,33**	1				
OV7	-,16	-,20*	-,26**	,07	,02	-,06	-,20*	-,35**	,02	-,05	,22**	,10	-,10	,14	,12	,21*	1			
OV8	-,40**	-,36**	-,28**	-,14	-,21**	-,04	-,22**	-,33**	-,10	,05	,53**	,28**	,04	,47**	,32**	,34**	,38**	1		
OV9	-,54**	-,59**	-,60**	-,43**	-,40**	-,34**	-,50**	-,28**	-,24**	-,27**	,51**	,38**	-,13	,46**	,48**	,32**	,36**	,44**	1	
OV10	-,34**	-,34**	-,37**	-,32**	-,21**	-,18*	-,23**	-,22**	-,10	-,03	,44**	,44**	-,02	,35**	,40**	,38**	,08	,47**	,50**	1

*=p<.05 **=p<.01

As Table 3 shows, all correlations between risk variables have a positive sign and almost all of them are statistically significant (*p*<.01). The risk variable *RV*5 (Falls from height), and *RV7* (Process) present the highest coefficients with all risk variables. *RV*10 (Auxiliary resources and machinery) obtained the lowest coefficients and relationship between *RV*10 and *RV*8 (Personal protections) was non-significant.

Relationships between risk and organizational variables showed that *OV*1 (*complexity* of the project) and *OV*2 (size of site) obtained negative correlations with all risk variables. Correlations among *OV*1 and *OV*2 and variables of resources (*OV*4, *OV*5, *OV*8, *OV*9 and *OV*10) have significant positive coefficients in most cases, and a similar pattern was obtained for *OV7* (job planning and design). However, *OV*3 (stage characteristics) obtained a significant positive relationships with most risk variables. The other relationships between risks and organizational variables (*OV*4, *OV*5, *OV*8, *OV*9 and *OV*10) obtained a more homogenous behaviour. Most of the correlations in this case were negative. Results about OV intercorrelations showed that *OV*1 (more complexity of the project) is statistically significant correlated with *OV*2 (size of site), *OV*4 (promoter resources), and with *OV*8, *OV*9 and *OV*10 (resources on site, preventive resources of coordinator, and H&S plan). *OV*3 (stage characteristics) did not reach statistical significance with any other OV variables, while *OV*7 (job planning and design) only obtained a significant correlation with *OV*8 and *OV*9.

1.4.2.1. – Relationships between CONSRAT and QRAM variables

Five of the nine Risk Levels (RL) of QRAM model to estimate correlations between CONSRAT variables were identified. It involves falls (F), contact with electricity (Ce), injured by falling/dropped/collapsing objects (Fo), hit by rolling/sliding object or person (So), contact with machinery moving parts (M). The four remaining RL were discarded due to their very low risk level magnitude. The risk assessment with QRAM was carried out without consider climate. All correlations between CONSRAT risk variables (RV) and QRAM risks levels (RL) were positive and mainly statistically significant (p<.01) (Table 4). Specifically *RV*5, falls of height, obtained highest coefficient of .92 (p<.01) with QRAM RL falls of QRAM. A similar behaviour was found between *RV*5 and the rest of RL variables (*RV*1, *RV6, RV*7, *RV*8 and *RV*9). A column with the average of all RV (SRI) was added in the middle of Table 4.

Table 4.- Correlations between CONSRAT variables and QRAM risk levels.

	RV1	RV2	RV3	RV4	RV5	RV6	RV7	RV8	RV9	RV10	SRI	OV1	OV2	OV3	OV4	OV5	OV6	OV7	OV8	OV9	OV10
F	,61**	,49**	,68**	,52**	,92**	,53**	,75**	,57**	,66**	,37**	,85**	-,18*	,06	,36**	,02	,01	,07	,04	-,14	-,28**	-,16
Ce	,47**	,73**	,61**	,53**	,55**	,32**	,58**	,29**	,44**	,23**	,64**	-,16	-,27**	,26**	-,41**	-,22**	-,21*	-,05	-,21*	-,39**	-,28**
Fo	,22**	,17*	,16	,26**	,47**	,66**	,45**	,37**	,13	,32**	,39**	-,10	,33**	,07	,04	,35**	-,08	-,13	-,10	-,17*	,01
So	,42**	,34**	,45**	,44**	,60**	,36**	,56**	,27**	,42**	,25**	,56**	-,10	,01	,37**	,03	-,02	,06	,04	,17*	-,17*	,09
M	,38**	,11	,28**	,07	,46**	,34**	,36**	,31**	,29**	-,11	,33**	-,14	,30**	-,13	,23**	,06	,21**	-,01	-,02	-,21*	-,01

*=p<.05 **=p<.01

1.5. - Discussion and conclusions

The main objective of this paper is to develop a new assessment tool that consider construction site as a unit of analysis, and the main idea that potential risk synergies may exist when individual risk elements are together on site. Consequently, the construction site risk is greater than the simple addition of the different risk levels identified from a hierarchy of events. Adequate convergent validity evidences for CONSRAT has been obtained using QRAM for correlation comparison. On one hand, a positive and statistically significant relationship between all CONSRAT risk variables (RVs) within and with QRAM risk levels (RLs) was expected, with different magnitudes depending of each risk variable composition. On the other hand, different relationship patterns between RVs and RLs with CONSRAT organizational variables (OVs) were expected depending of the OV type. In general, for OVs that express complexity (*OV*1, *OV*2, *OV*3, *OV*6 and *OV*7) a positive relationship with RVs and RLs was expected, in the sense than more complexity increase risk. With OVs that express resources (*OV*4, *OV*5, *OV*8, *OV*9 and *OV*10) a negative relation with RVs and RL was also expected, in the sense that more resources decrease risk. And finally, lower coefficients or even non-significant relationships between RLs and OVs than with RVs and OVs were expected, because the most general site assessment that entails RVs.

Results of correlations among RVs confirm expected results, so adequate evidences about all RVs could be representative to site risk level have been obtained; though RVs are assessing different risk site areas. Particularly, RV5 (falls from height) and *RV7* (Process) results are mainly demonstrative in our context of building construction sites, that are indicative of site level risk. These two variables showed statistical significant correlations

(p<.01) with all other VRs and RLs, and may justify they election of variable composition. For its part, RV6 (Other risks) also reached significant correlations with all others RVs and RL, despite their coefficients are lower than with RV5, that shows its adequacy and adequate behaviour. The lowest coefficients of RV10 with the others RVs, although significant, show certain independent relationship, as for example, with *RV*8 (Personal protections). In this case, the site can have a good fall protection system, but also have inadequate machinery, or vice versa.

Obtained correlations among RVs and OVs are important empirical evidences about the CONSRAT internal consistence (not psychometric one). Correlations between RVs and OVs agree in general with our expected results, but not in all cases. Significant relationships of variables *OV*1 and *OV*2 with most of RVs are negative, that means more complexity may be related with lower risk. These results could be interpreted in the sense that probably more complex projects with bigger sites have more resources to control their risks. In fact, positive correlations from both *OV*1 and *OV*2 to resources' OVs (*OV*4, *OV*5, *OV*8, *OV*9 and *OV*10) confirm this prevision and explain previous results. A similar behaviour for both *OV*7 and *OV6* than *OV*1 and *OV*2 with RVs (although with lower coefficients) may think in similar motivations because the similar correlations with OVs of resources. Correlations of *OV*3 on RVs agree with expected results. These evidences give support to the strength of OV structure to assess stage complexity and its possible relation with risk. On the other hand, expected results among resources variables (*OV*4, *OV*5, *OV*8, *OV*9 and *OV*10) on RVs were also obtained. Especially adequate behaviour between the OVs related with prevention (*OV*8, *OV*9 and *OV*10) was showed, with the best behaviour of *OV*9 (preventive functions) to RVs. These results are indicative of content validity of the tool, and in addition of the importance of resources, especially the preventive functions of the structure, over the complexity of site.

Intercorrelations between OVs showed an adequate expected behaviour. All correlations between different dimensions of site complexity (*OV*1, *OV*2, *OV*6 and *OV*7) are positive and most of them significant, except *OV*3 that has a different pattern because the specific characteristics of the stage that could not be coincident with site complexity in each stage. These results can be interpreted as these variables assess different characteristic of complexity. And taking into account the sample, composed by building constructions, these OVs assess characteristics that have a similar behaviour. For example, among the significant correlations (p<.01), more complexity of the project (*OV*1) are related with more size (*OV*2) (.41), and job planning and design (*OV*7) (.22). More complexity also implies more works on site, more workers among others. But *OV*1 and *OV*6 (Internal organization structure) do not have a similar pattern with no significant results, like *OV*1 and *OV*7. These results could be interpreted as a lack of proportion among the complexity of site and the complexity of its organization and planning. More big or complex sites do not have more subcontracting or more complexity of contracting as it could be expected; so, a possible excess of these two issues in small sites.

The obtained correlations between dimensions of resources (*OV*4, *OV*5, *OV*8, *OV*9 and *OV*10) showed more consistent results than previous of complexity. Most correlations are positive and significant (p<.01) and have higher values (ranging from .33 to .50). According with these results, these resources variables show internal coherence although they assess different characteristics. Furthermore, positive and significant correlations among OVs of resources and OVs of complexity fitted the expected behaviour because sites with more complexity in general have more resources. OVs expected intercorrelations are indicative of the adequate structure of these variables and show the broad possibilities of the tool.

Discussing the values of correlations among RVs (CONSRAT) and RLs (QRAM), important convergent validity evidences are obtained as most of them are significant (p<.01) and positive as expected. Correlations with the Site Risk Index (SRI) are also significant and positive as expected with all RLs, and also for the five alarm RVs (*RV*1, *RV*3, *RV*5, *RV*8, *RV*9). As it was also expected, the best coefficient is obtained for variables that assess the same risk (i.e., *RV*5 and RL_F). In more detail, RL_F (falls) obtained the highest values with *RV*5 (Falls, .92), *RV*7 (Process, .75), *RV*3 (General collective protections, .68), and *RV*9 (Personal fall protection, .66). It is important to highlight the strong positive relationship between RL_F and *RV*7 that shows the relevance of the process (adequacy and deviation) in relation to the existence of fall risk and let us to focus on check what happens in the sequence of tasks that is associated with high levels of risk. For its part, relationship between RL_F and both *RV*3 and *RV9* connects the general collective protections and personal protections with risk of falls in main work. All these RVs strongly correlated with RL_F can directly focus the problem involved and try to correct in the genesis. Other relations are relevant too, as for example the relationships of RL_F with *RV*1 (H&S plan compliance) (.61) or with *RV*8 (Collective protections on stage) (.57).

As some RLs are in part assessed in some RVs, they obtain significant (p<.01) and positive correlations. For example, RF_Ce (contact with electricity), obtained the highest coefficients with *RV*2 (general conditions; .73), RL_Fo (injured by falling/dropped/collapsing objects) obtained higher coefficients with *RV*6 (other risks, .66) and RL_So (hit by rolling/sliding object or person) with *RV*3 (general collective protections; .45). Other important strongly correlation is between all RLs and *RV*7 (process) positive and significant (p<.01) in cases, and with high coefficients (Ce .58, Fo .47, So .56 and M .36). We interpret these results, as the case of fall (RL_F), in the sense that *RV*7 is a strong predictor of future risks, capable to anticipate them just checking the adequacy of the process without need of risk manifest. These results probably imply to reconsider this variable as one more of alarm variables. Similar behaviour showed *RV*5 (Falls) with all RVs, with positive sign (p<.01), with biggest coefficients with RL_F, RL_So (.60), RL_Ce (.55), RL_Fo (.47), and RL_M (.46). According to these results, *RV*5 could be an adequate indicator capable to advance information of the general risk level on site. These results pointed out that RVs could contribute to assess overall site risk level, which was one of the important goals of this study. They also lead to conclude that, in this type of building sites, one can use falls from height as unit of measure or an indicator of general site risk, as it correlates with the major of rest important risks on CONSRAT as well as on QRAM used for validation. RVs are capable to detect the appropriateness of safety barriers (Ale et al., 2008) as well as accident precursors or leading indicators (Grabowski et al., 2007; Hinze, Thurman, et al., 2013; Toellner, 2001).

In general, a different behaviour than the relationships between RVs and OVs was expected. For example, RF_F (falls) shows a significant positive correlation with *OV*3 (Stage characteristics), that is strongly coherent, because stage characteristics are directly affecting this risk. The same pattern happened between RL_F and *OV*9 (preventive functions), more integration of preventive functions implies low risk levels, with a negative and significant coefficient (-.28, p<.01). A similar relationship is found between *OV*9 and the rest of RLs, significant and negative with different magnitude coefficients. Correlation between RL_F and *OV*1 is negative and means that the complexity of the project impacts negatively on fall risk (the same behaviour than *OV5* on *OV1*) that can be explained by the existence of more resources (mainly as the commented relationship with *OV*9). For its part, RL_Ce obtained a significant correlation with 7 OVs, with best results with resources OVs, mainly with *OV*4 (promoter resources, .41), *OV*9 (preventive functions, .39), *OV*10 (H&S plan adequacy, .28), and *OV*8 (coordinator resources, .21). In all cases resources has an impact to better risk conditions.

Finally, regarding to practical application, CONSRAT requires a simpler assessment process than QRAM and is easier to be carried out by any technician with previous basic training. And the most significant difference between CONSRAT and QRAM or other similar tools of risk assessment is that CONSRAT considers site risk elements, agents and resources, having an overview of "the construction site" and its environment. It can be used both as a tool for previously risk assessment, and to verify the site risk level regularly. In this sense, it can be considered as an active leading indicator or predictor (Grabowski et al., 2007; Hinze, Thurman, et al., 2013). It can be used as a site safety audit. It can also be used as many times as desired in order to monitor and assess proposed improvements.

This instrument tries to meet the lack of tools for analysing the construction site as unit of analysis, with own identity characteristic that affect risk. CONSRAT adopts a site risk approach through the building of several variables to assess the main live conditions, complexity factors and organizational structure characteristics which are related to risk. It makes possible a subsequent analysis of the relationships among those variables, therefore, to guide potential intervention programs to enhance safety and health.

1.6. - Limitations and future challenges

CONSRAT has been designed to assess building construction sites and organisational structures in the European environment. Other environments or site types may need an adaptation of the tool contents. Although CONSRAT has elements to enhance the objectivity of the assessment, it is necessary provide previous training for inspectors. Law knowledge and experienced technical criteria are imperative to correct manage this tool. CONSRAT has been design to easily collect data while visiting the sites. As a future extension, we programme to build an application for mobile devices to further inspections on site. Finally, we point out that CONSRAT is an easy manage instrument to assess site risk and mainly oriented to focus intervention on most important issues capable to affect risk, including material conditions as well as complexity or resources specific of construction sites.

1.7. - Acknowledgements

This tool has been awarded as the best poster by the Scientific Committee of the XV International Conference on Occupational Risk Prevention (ORP) that was held in Santiago de Chile in November, 2015. This research was partially founded by the project ECO2013-48496-C4-1-R of the Spanish Ministry of Economy and Competitiveness.

2. - The impact of organizational complexity and resources on constructions sites risk.

2.1. - Abstract

Our research is aimed to study the relationship between risk level on constructions sites and organizational complexity and resources. Our general hypotheses are that site complexity increases the risk, whilst more structure resources decreases the risk. A Structural Equation Model (SEM) approach was adopted to validate our theoretical model.

To develop our research, we have visited and assessed 957 building sites in Spain during the period 2003-2009. All needed data were obtained using a specific tool developed by the authors to assess site risk, structure and resources (Construction Sites Risk Assessment Tool, CONSRAT). This tool operationalizes the variables to fit our model, specifically, a site risk index (SRI) and 10 organizational variables. Our random sample is composed manly by small building sites with general high levels of risk, moderate complexity, and low resources on site.

The model obtained adequate fit and results showed empirical evidence that the factors of complexity and resources can be considered as predictors of sites risk level. As a consequence, this results can help companies, managers of construction and regulators to identify which organizational aspects should be improved in order to prevent the risks on sites and consequently accidents.

Key words: risk site, construction, organization, complexity, resources, structural equation model.

2.2. - Introduction

Originally, most Health and Safety (H&S) research on construction began by highlighting the accident rates problem as well as the special nature of construction (Baxendale & Jones, 2000; Cheng et al., 2010; Mahmoudi et al., 2014; Wu et al., 2015). At the same time, it seems that there is something intrinsic in construction sector that produces these risks. Currently, risk level assessment research has evolved from an accident-based approach towards a more prospective and holistic one, characterised by technical analysis adding organization and human factors (Sgourou et al., 2010). Despite this tendency, most of the current research is still based on accidents (Hollnagel, 2008; Khanzode et al.,2012). Thus, there are a small number of studies where authors use precursor analysis as an alternative to classical accident approach. These authors criticize about reactive research techniques that use lagging indicators and they propose different leading indicators (predictors) to obtain information before an accident occurs (Grabowski et al., 2007; Hinze et al., 2013; Rozenfeld et al., 2010; Sparer & Dennerlein, 2013; Toellner, 2001). In this research we try to link organization variables with risk in order to propose them as another set of predictors of risk.

Organisational factors have arisen as a relevant issue for site risk research. Since Hoewijk (1988) proposed that the vertexes of the “Organization Triangle” formed by structure, culture and processes, are mutually dependent and conform workers behaviour, others models and metaphors represent the accident process (Swuste et al., 2012, 2010) and have analysed this organisational side of the problem of safety. One important is the Bowtie metaphor (Visser, 1998) identifies preventive measures, before the loss of control of the accident process, and the mitigating measures, which can reduce injury and damage (Hale et al., 2004). This metaphor clarifies the important relationship between management and the scenarios were hazards become in risks. Management identifies risks, select barriers and determine the effectiveness of them (Swuste et al., 2012). This metaphor is the basis for developing Workgroup Occupational Risk Model (WORM) based in accident scenarios for cover the full range of occupational accidents (Hale et al., 2007). For each accident scenario the items selected for accident modelling with the "Storybuilder" (the tool to classify and analyse accidents) included among others the management failures in terms of failed control or resources (Baksteen et al., 2007; Bellamy et al., 2008, 2013). This approach is complex for construction companies because the especial features of the sector as, for example, the temporary nature of sites, their physical distance from company headquarters, the low level of standardization of processes and so on (Wilson, 1989). Besides this, the sector is also characterized for the special conditions of agents structure, business processes and operational levels (Donaghy, 2009; HSE, 2009). For Swuste et al. (2012) construction companies are similar to an organic structure that manifests itself in its processes. Although process may determine the organisational structure on site, the resources of the head company are determinant to guarantee enough site resources.

There is a certain consensus about the relationship between organisational factors and risk conditions. In fact, a selection of nonspecific construction risk conditions assessment methods was analysed by Sgourou et al. (2010) and all of them include organisational features. But a low number of field research, specifically on construction sites, have connected and concrete these relations (Fang et al., 2004; Mohamed, 1999; Swuste et al. ,2016; Teo & Ling, 2006; Wu et al., 2015) and even fewer have linked organisational and complexity with risk level assessed on site (D. P. Fang, Huang, et al., 2004).

The normative is other important dimension to analyse the relationship between H&S and firms' organizations structure. H&S Laws have been incorporated in Europe from 1990s through European Directives. These make a new framework for all different agents intervening in the processes (Ros Serrano et al., 2013) that should generate an adaptation within companies' structure, principally of H&S human resources and the functions of contractors and subcontractors, to comply with the new preventive model required. But most companies only complied with formal aspects of the H&S Law in terms of fulfilment of required documentation.

"Safety has become too bureaucratic. With the slogan 'manage the risk, not the paper work' HSE calls for a return to the controlling of hazards and risks at construction sites …" (Swuste et al., 2012)(p.5).

2.3. - Literature review

2.3.1. - Risk and organizational parameters at constructions sites

Most research tries to find connections between different aspects of safety performance (SP) and safety management systems and wider organizational issues (Bellamy, 2009; Bellamy et al., 2008; Jørgensen, 2016; Niskanen et al., 2016; Wang et al., 2016). On the one side SP is a concept under investigation that very few empirical studies have analysed (X. Wu et al., 2015). According to Ghasemi et al. (2015) SP has two aspects: risk conditions (e.g. working conditions, protections, procedures and rules) and safety participation (e.g. motivations, safety meetings participation). On the other side safety management systems are a broader organizational concept that includes among others practices, policy, meetings, etc.

Table 1 presents a summary of the literature review. Each authors' study is described depending on the index they have created.

Table 1.- Summary of literature review with organizational and H&S indices

Author	Organizational index	H&S index	Methodology	Results
Mohamed (1999)	SMI: policy, management declaration, meetings, internal audits training and awareness programs	SPI: SP records, subcontractors in safety discussions, planning with hazards, personnel's rewards, trained safety officers and record of intoxications	Correlation analysis and cluster analysis	No significant positive correlation
(D. P. Fang, Huang, et al., 2004)	SMI: project nature, historical factors, organizational structure, management measures, individual involvement, economic investment, relations between labour and management on site	SPI: inspection records of physical safety conditions, satisfaction of site personnel and accident frequency	Regression analysis. Direct field work information	Organizational structure, economic investment, and relations between labour and management were significantly related to their SPI
(D. P. Fang, Xie, et al., 2004)	11 factors identify and 5 correlated	Safety management performance	Factor analysis	Foreman, worker, crew, manager and safety training were prioritized with safety management performance
Teo & Ling (2006)	SMS: safety management system	CSI: measured through: Policy, Process, Personnel and Incentive factors	Analytic Hierarchy Process (AHP) and Factor analysis	Ineffective SMS can be identified through low CSI scores
Fernandez-Muniz et al. (2009)	Safety management	Firm organizational performance through Accidents statistics	Factor analyses, and confirmatory SEM	Safety management has a positive influence on SP, competitiveness and economic performance
Toner & Pousette (2009)	Safety management: set of organizational measures	Preconditions on H&S on site	Survey to experienced workers and first-line managers	Project characteristics; Organization and structures, with planning, work roles, procedures, and resources; Collective values; and Individual competence and attitudes
Manu et al. (2010)	Identify accident causal factors CPF	To connect with accident prevention	Literature review	Nature of project, method of construction, site restriction, duration, procurement system, design complexity, level of construction and subcontracting

Cheng, Ryan, & Kelly (2012)	SMP: safety management practices, perceptions	Project execution performance	Exploratory factor analysis and regression	Safety management process, followed by safety management information and committees
Wu et al. (2015)	Safety climate, culture, attitude and safety behaviour	PSPE, Prospective safety performance evaluation, assess thought historical evidence of accidents and safety records of inspections	SE M	Different levels of SP given the firm scale. Better level Sino-foreign joint ventures, second state-owned enterprises, last the private firms

As we can see in Table 1, SP as well as safety management includes several elements, depending of each author's definition. Each study focuses on one set of issues related with these terms, e.g. Törner & Pousette (2009) pointed out that any study of safety management must to develop a set of organizational measures reported at the Table. Manu et al. (2010) defined Construction Project Features (CPFs) like the elements that linked to accident causation. These authors literally expressed:

> *"These CPFs are organisational, operational, and physical attributes that characterise construction projects, and they emanate from the client's brief, project management decisions and design decisions. Like other distal/originating influences in construction accidents, the above-mentioned CPFs are high level determinates of the nature, extent and existence of immediate causes of accidents…."* (p. 688)

Despite the important connection between SP and safety management recognized in the literature, we observe a lack of empirical evidence between relationships of these issues (Knegtering & Pasman, 2009; Körvers & Sonnemans, 2008; Swuste et al., 2016), and the different contents of both them. Due to the lack of a common and narrow definition of the concept of SP, we have focused in the assessment of the site risk. In relation to safety management, and taking into account our model of risk site assessment, we just focus on organizational structure and resources of safety management.

Based on studies reported at Table 1, we propose in Table 2 the following factors of complexity and resources on site.

Table 2.- Factors and corresponding research references

Factors	Research references
F1. Site complexity	(Fang, Huang, et al., 2004; Forman, 2013; Hatipkarasulu, 2010; Hon et al., 2010; Manu et al., 2010)
F2. Firm's structure resources	(Abudayyeh, et al., 2006; Baxendale & Jones, 2000; Behm, 2005; Camino López et al., 2011; Camino López et al., 2008; Cheng et al., 2010; Fang, Xie, et al., 2004; Hinze et al., 2013; Holte et al., 2015; Liao & Perng, 2008; Pérez-Alonso et al., 2011;Ros et al., 2013; Wu et al., 2015; Xinyu et al., 2006)
F3. Site structure complexity	(Fang, Huang, et al., 2004; Hinze et al., 2013; López-Alonso et al., 2013; Manu, et al., 2013; Swuste et al., 2012; Yung, 2009)
F4. Safety Management resources	(Adam et al., 2009; Baxendale & Jones, 2000; Borys, 2012; Fang, Huang, et al., 2004; Jarvis & Tint, 2009; Mahmoudi et al., 2014; Manu et al., 2013;Ros et al., 2013)

2.4. - Theoretical model and hypotheses

2.4.1. - Model

Based on technical knowledge and the evidence found in the previous literature, we propose to assess to what extend the risk on sites can be explained from the level of two organizational factors, complexity and resources. Our proposal is that risk on site, in addition to the classical definition of the combination of probability of exposition to the hazards and the consequences, can be explained in part as a function of both factors as expression (1) contains:

$$\boldsymbol{Risk} = \boldsymbol{f}(\boldsymbol{complexity}; \boldsymbol{resources};\ \mathcal{E}) \qquad (1)$$

Where Ɛ contains all other factors affecting risk on site.

Our model of risk connection and its empirical test are presented here as one of the major contributions of our research. Table 2 shows the factors classification attending literature review. This general classification of factors has been also confirmed by an expert panel as we will report below. We have excluded for our analyses those factors that even being considered in the literature, did not apply to the sample, our research purpose, or which were explicitly excluded by our expert panel. The specific names of each factors and variables are just illustrative of their content according to the literature reviewed, we are not proposing here an accurate definition or measurement of each concept.

2.4.2. - Hypotheses

Following we connect the main important elements coming from literature review that are used to build the factors and the corresponding hypotheses.

F1) Site complexity

Complexity of site is an important factor affecting risk conditions. This complexity is measured looking at type of project (considering works on repair, maintenance and extension) (Hon et al., 2010), high risk typologies (Hatipkarasulu, 2010), other project elements (type of work, site restrictions, design complexity and the level of construction) (Manu et al., 2010), and finally the project nature (size of site, complexity of construction) (Fang et al., 2004). Some of them increase fatal accidents such as falls from height (which represent 50% of fatal accidents from 1996-1997 to 2007-2008 according to HSE (2009).

We propose to include in this site complexity factor the variables of complexity of the project, size of site and stage characteristics. Therefore our first hypothesis is:

H1: Site complexity (e.g. bigger sites, more height, etc.) increase risk on site.

F2) Firm's structure resources

One of the organization variables receiving more attention has been company size. But there is not consensus about his relationship with probability of accidents. Liao & Perng (2008) found that more size is related with more accidents while other studies converged to the contrary (Camino López et al., 2011, 2008; Holte et al., 2015; Pérez-Alonso et al., 2011). There seems to be evidence showing that small companies' size and private projects with low budgets, have a strong correlation with accidents (Cheng et al., 2010)

Type of promoter as well as construction companies are also linked with construction safety (Ros et al., 2013; Baxendale & Jones, 2000; Behm, 2005; Fang et al., 2004; Hinze et al., 2013; Xinyu et al., 2006; Wu et al., 2015). Promotors mainly defined several practices related with technical controls on sites, and constructors related with scale, ownership, foreman and crew on site.

We propose to include in Firm's structure resources factor the variables reflecting promoter's and constructor's resources respectively. Therefore our second hypothesis is:

> **H2: Firm´s structure resources (e.g. promoter and constructor's resources) decrease risk on site.**

F3) Site structure resources

Subcontracting and the coexistence of different agents, each of them with their own characteristics and role, add complexity and make the site more difficult to manage. This is associated with low levels of safety (J. Hinze, Thurman, et al., 2013; López-Alonso et al., 2013; Manu et al., 2013; Swuste et al., 2012; Yung, 2009). For example, there is a connection between the average number of accidents and the total number of workers, the average number of subcontractors and the health and safety budget. Manu et al. (2010) included some references to the complexity of contractual system and players (different agents involved in procurement) as responsible of adding risk in the construction sector.

We propose that our factor of Site structure resources includes a variable to capture the internal organizational structure and other variable to cover different aspect of the job planning and design. Therefore our third hypothesis is:

> **H3: Site structure complexity (e.g. bigger number of workers, more number of firms, more levels of subcontracting, etc.) increase risk on site.**

F4) Safety management resources

The preventive functions of the person in charge are a problem especially for small companies where they are delegated to one employee in addition to other responsibilities (Jarvis & Tint, 2009). This is a problem that directly affects the possibility of H&S control. The general answer must be to integrate H&S into the day to day activities of the company. The problem is to find a specialised worker, and how to assign his prevention functions (Baxendale & Jones, 2000). One alternative is to have a non-working subcontractor's foremen who have direct responsibility for the safety of workers in their tasks (Manu et al., 2013), or just with the existence of specialised human resources but also considering the strong commitment for management (Abudayyeh et al., 2006). In a similar approach Fang, et al. (2004) analysed the management resources and H&S on site (safety supervisors, their authority, and involvement of contractor management, foreman authority, safety inspections, including those carried out by owner's initiative, safety plan and records). Those owners' safety inspections are referring to the coordinator (H&SC, European Directive 92/57 CEE), a relevant factor in safety management, in addition to the authority of safety supervisor and foreman (Ros et al., 2013).

Other studies put at project level the most relevant influences on H&S on site (Mahmoudi et al., 2014). Elements as processes and resources are needed to obtain adequate safety levels (Adam et al., 2009; Borys, 2012). These are the most important elements that any

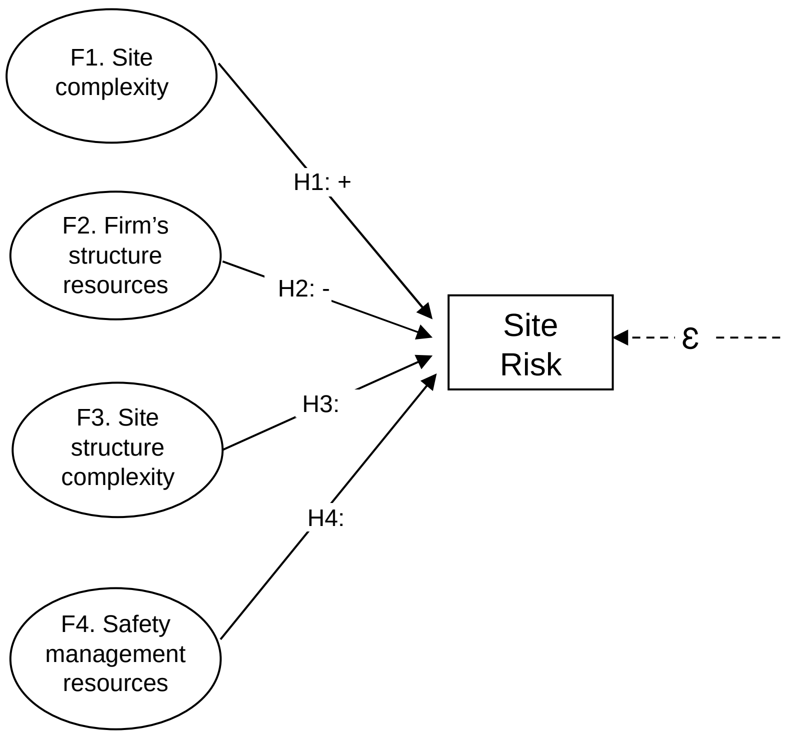
H&SP (H&SP) should incorporate, and this document is the essential reference regarding the H&S previsions on sites.

According to the evidence reviewed, we propose the safety management resources factor to be composed by three different variables: coordination resources, preventive resources and finally, H&SP. Therefore, our fourth hypothesis is:

> **H4: Safety management resources (e.g. H&SC, preventive functions and H&SP) decrease risk on site.**

Our simplified theoretical model of organizational and resources influences on risk level on constructions sites are shown in Figure 1. We propose that site risk is related with "Site complexity" (positive relationship), "Firm´s structure resources" (negative relationship), "Organization design complexity" (positive relationship) and "Safety management resources" (negative relationship). At some extent, those factors can be taken as predictors of site risk. But as it is known, any risk is related with a more complex and multiple combinations of hazard expositions. In our model, it is represented by discontinuous arrow identified by Ɛ, which means all others elements affecting site risk. Because our goal is to verify whether the resultant level of risk, product of this exposure, is related or not with certain levels of our proposed organizational factors.

Figure 1. Simplified model of SRI influences on site.



2.5. - Methods and materials

2.5.1. - Data collection

All our data come from specific field work using CONSRAT (see Paper 1, chapter 1), which had been developed as part of a broader research project. This tool, using the construction site as a unit of analysis, assess the site risk level and some organizational elements on site relevant for H&S. The tool gather information such as site characterisation, promoter and contractor characteristics, available documentation, general conditions, the specific risks on the stage, the protections, the processes and the auxiliary resources and the machinery. CONSRAT variables are used in the present study to analyse the relationships between risk and organizational variables.

Data collection using CONSRAT entails a four step process. First step begins with a field visit to the site, then an interview is carried out to the person in charge (either site foreman or responsible person), after that a checking of the documentation that must be on the site (e.g. H&SP, incidents book, subcontracting book) is undertaken. We have to review each document and compare it with the current stage observance. For example, for H&SP, we have to check the previsions for present stage including protection, process, access, etc. to be able to answer the corresponding items related with this document; for incidents book, the possible annotations affecting current works; and, for subcontracting book, we have to identify the firms on site and their contractual relationship. The second step implies to gather all general data of the construction site, let us say, the items for the organisational variables. After this, the third step comprises a general visit to the construction work in order to observe and check its general common elements (i.e. enclosure, accesses, cleanliness, general machinery, general protections, etc.). Finally, the fourth step requires make a visit to the specific stage location to evaluate its specific conditions (i.e. accesses, risks, protections, etc.).

Using CONSRAT we collected information and data regarding live conditions and organizational issues visiting a total of 957 sites, mostly building construction in Mallorca (Balearic Islands). All those sample's sites were selected following a random criteria, rejecting any site visit than might be caused by any type of special H&S event, as for example, an accident, a complaint, or similar. All the field work was carried out by the same technician and data were collected from 2003 to 2009.

CONSRAT registers data and assessments to a total of 97 questions or items; 60 of them are the source to build our 10 risk variables and 22 items compose our 10 organizational variables (see Tables 6 and 7, section 4.2 and 4.3). The rest items are general site information and instrumental data. The 10 number of organizational as well as risk variables should not be taken as a closed number, but an approximation of important parameters to characterize site risk and complexity or resources on site.

2.5.4. - Organizational variables

Table 3 illustrates the structure of our organizational variables OV and factors system. Based on CONSRAT's OVs, we have classified them as pertaining to one of the factors or latent variables according with literature review (see Table 2, section 2.1) and expert consultation. Each OV is composed with some relevant items driven from empirical studies from a pool of a total of 22 items coming from CONSRAT.

In order to confirm our classification and to derive a weight for each of the item that conforms any of the OV, we carried out an expert panel consultation. We formed an expert panel meeting with 11 individuals. All participants were experts with more than 15 years of experience on construction. Six of them had professional experience as projectors and/or directors of several buildings constructions assuming safety and health functions. Five of them, in addition, had academic experience training in architecture or engineering subjects, including specific training on safety and health subjects. We asked them for to classify all the 22 different items into one of the factors mentioned above. They were not forced to assign all the items to a given factor, i.e., they were allowed to not classify any of them if they thought there was no logical, technical or theoretical reason to do so. The result was that the experts correctly assigned all the given items, and consequently their associated variable, to the factor previously considered by us, except in two items. The two non-concordant items were “Type of promoter firm resources” and “Number of works”. In the first case 64% of experts disagreed with our previous classification whilst 27% agreed and 9% of them did not classified that item within any factor. Regarding “Number of works”, only 9% of experts shared our a-priori classification while the remaining 91% of experts classified this item in other factors, specifically, 73% in factor F3 and 18% in factor F4. In both cases, we changed our a priori classification maintaining the one supported by the panel of experts. The resulting final classification of each item/variable within their corresponding factor in our model was supported by an average of 78.73% of the experts (SD=12.89).

For a second request, we asked the experts panel to assess the degree of importance of each item that composes each variable on safety prevention on site. Specifically we asked them: “To what extent do you consider this item as an important driver (or determinant) of prevention level?” We gave them a Likert scale ranging from 1 (null) to 7 (total) to assess the importance degree of each item. Column “Importance degree” in Table 3 reports these results of the expert panel consultation (the average rating for each item and the standard deviation of experts’ responses). Then, we have transformed the “Importance Degree”, into a “Derived weight” (see last column in Table 3) in order to build each OV. In doing so, we used the ratio weighting technique to derive each item weights from the experts’ declared rating of relative importance (Edwards, & Newman, 1982). With this technique we obtained a relative weights set, normalized to range from 0 to 1, referring the relative importance of each item in every OV (weights inside each variable sum 1).

Table 3. Key organizational factors, variables and their items

Factors	Variable	Item	Importance degree (SD)	Derived weight
F1. Site complexity	OV1. Complexity of project	1. New work site or reform and extensions	5 (1.7)	.32
		2. Building Configuration	4.63 (1.85)	.29
		3. Special environment conditions	6.1 (0.75)	.39
	OV2. Size of site	4. Number of floors	5.27 (0.79)	1.00
	OV3. Stage characteristics	5. Main work stage	5.4 (1.04)	.50
		6. Secondary work stage	5.4 (1.04)	.50
F2. Firm´s structure resources	OV4. Promoter resources	7. Type of promoter firm resources	3.7 (1.79)	1.00
	OV5. Constructor resources	8. Type of construction firm resources	5.64 (1.21)	.32
		9. Resources depending of Constructor’s Role	5.7 (1.21)	.34
		10. Site management structure	5.7 (0.79)	.34
F3. Site structure complexity	OV6. Internal organization structure	11. Type of contracting	5.8 (0.87)	.36
		12. Number of companies	4.9 (1.29)	.30
		13. Level of subcontracting	5.4 (1.29)	.34
	OV7. Job planning and design	14. Number of woks	5.6 (1.03)	.27
		15. Employer location assignments	5.8 (0.87)	.28
		16. Total number of workers at site	4.9 (0.65)	.23
		17. Ratio of number of workers of principal	4.7 (0.9)	.22

		constructor over total workers at site		
F4. Safety management resources	OV8. Coordination resources	18. Designation Health and safety coordinator	5.3 (1.42)	.49
		19. Documented work H&SC	5.5 (1.57)	.51
	OV9. Preventive functions	20. Preventive functions of the structure	6.2 (1.10)	1.00
	OV10. Health and safety plan	21. Presence at site	5.37 (1.80)	.45
		22. Appropriateness of H&SP's previsions	6.7 (1.65)	.55

Appendix A-2 contains a summary of the metrics and scales used for measuring all items considered in our research. Thus, in all cases a higher observed value implies more complexity (e.g. value 1 in item "Building configuration" is associated with less complexity than an observed value of 4 in that item) or more level of resources (e.g. a case with value 1 in the item "Promoter resources" is considered as having lower level of resources than those cases with a value of 3 in that item). In order to have all the different items measured in a common scale, we transformed the original observed values into percentiles according to its own range of measurement scale. With those values for each item and the derived weighting vector of Table 3, we calculated the value of each organizational variable as the weighted average of observed values in percentiles of its corresponding items. Those are the observed data of our independent variables which are considered for our structural equation model test. Summary statistics of all our variables are included in Appendix C-2.

2.5.4. - Risk variables

Table 4 shows RVs composition. In our theoretical model the dependent variable is the Site Risk Index (SRI). Based on literature review, authors' technical judgement which is grounded with more than 25 years of professional and technical experience in H&S inspections, and the previous tool validation (see Paper 1, chapter 1). We propose to calculate the SRI as the average of ten different RVs of COSNRAT. All they are derived directly from the work conditions on sites.

According to our technical criteria and in order to have a more accurate assessment of risk in construction sites, we consider important to differentiate the two more relevant ambits at sites, the general conditions affecting the common elements and the specific condition of the construction stage. Another issue considered as relevant to measure risks is the existing processes and protections on sites (Hollnagel, 2008; Swuste et al., 2012), not explicitly considered in empirical risk assessment. Finally, our SRI captures the accomplishment of the H&SP, the most important reference of health and safety previsions on site, which is not included in the available tools in literature.

Table 4. Risk variables

Variables	Items
RV1.- Health and safety plan	1. Compliance.
RV2.- General conditions	2. Construction fence
	3. Circulations, order, tidiness, illuminations
	4. Safety signage
	5. Safety of electrical installation
RV3.- Collective protections	6. General collective protections. This item measures the general collective protections of site, without considering the current stage.
RV4.- Access	7. Access to main work. This variable measures the specific conditions of access to the main stage site, independent from general access

RV5.- Falls of height	8. Height of fall 9. Level of failure 10. Exposure continuation 11. Probability 12. Severity 13. Intervention required
RV6.- Other risks	14. – 24.- Identification of 11 more risks 25. Incidence with Falls of height
RV7.- Process	26. Type of process 27. Adequacy 28. Process deviation
RV 8.- Collectives protections	29.-30. Scaffolds. Adjustment to the phase and installation validation. 31.-32. Safety nets. Adjustment to the phase and installation validation. 33.-34. Railing. Adjustment to the phase and installation validation. 35.-36. Safety boarded. Adjustment to the phase and installation validation. 37. Necessity more Collective Protections.
RV9.- Personal protections	38.-39. Fall protection system. Adjustment to the phase and installation validation. 40. Necessity more PPE
RV10. Auxiliary resources and machines	41.-42. Scaffolds. Adjustment to the phase and installation validation. 43.-44. Suspended scaffolds. Adjustment to the phase and installation validation. 45.-46. Horse scaffolds. Adjustment to the phase and installation validation. 47.-48. Portable ladders. Adjustment to the phase and installation validation. 49.-50. Others. Adjustment to the phase and installation validation. 51.-52. Lift truck. Adjustment to the phase and installation validation. 53.-54. Crane truck. Adjustment to the phase and installation validation. 55. Fall protection for elevation resources. Adequate for the work. 56. Auxiliary resources for elevation system. Adequate for the work. 57.-58. Concrete mixer. Adjustment to the phase and installation validation. 59.-60. Manual tool. Adjustment to the phase and installation validation.

Each RV has a scale ranging from 0 to 1, where 0 means no risk and 1 means the maximum level of risk. More details of RVs composition and assessment scale are in Appendix B-2. The corresponding SRI has the same scale, because is the arithmetic mean of the 10 RV. The summary statistic of all variables and SRI are reported in Appendix C-2.

2.6. - Results

2.6.1. - Descriptive statistics of our sample

The highest percentage of our sample corresponds to multi-family housing (44.6%) followed by single family housing (43.9%). Most of the sites are buildings with two-three floors (60.7%), which represent normally from 6 to 9-12 meters of total height.

Promoters in our sample are mostly professional firms dedicated to construction (56.8%), followed by particular promoters (34.6%) and a minority of works lead by Public Administration (8.6%). Relating to construction firm, the most present type of companies were companies with different legal forms (86.4%) and less cases were found being any of the self-employed configuration (13.6%). Most of the sites have one contractor (company contracted directly by promoter, 83.1%) and more than one firm (58.9%). Sites with subcontracting represent the majority of the cases in our sample (54.8%). The mean number of workers in the sites of our sample is 13.82, with a mean for each company present in the same site of 5.12 workers.

If we consider the management structure of the sites, most of them have a person in charge. The 25.6% of the cases has a worker with organizational functions, the 25.3% of our sample has a foreman, the 14.8% has a business owner, and finally the 8.5% of the sites had two or more individuals with higher hierarchical rank. The remaining 25.8% of sites do not have anybody in charge.

In the majority of our sites there is not any documented H&SP (62.7%), and those most common work stages were flat structure works (34.8%) and brickwork (27.8%).

From the calculated levels of SRI from CONSRAT, we classify our sample in three levels that represent different risk situations: for values from 0 to 0.33 (included) we considered as correct, from 0.33 to 0.66 (included) as acceptable, and finally above 0.66 as critical. The distribution and meaning criteria of classification in our sample is reported in Table 5.

Table 5. SRI classification of our work sites

Classification	Scoring groups	Criteria of selection an mining
Correct	0-0.33	General well compliance of all variables. Barriers are well installed, reliable, and independent for the workers that can used it. Low levels of risk and general good conditions.
Acceptable	0.33-0.66	Appropriate, without critical failures. It could be some minor failures, but in overall compliance with the needed conditions.
Unacceptable	+0.66	Deficient, with critical failures on protections or lack of them. They are significant and could affect the barriers, the installation, the user or other persons.

2.6.3. - Statistical analysis

As we have mentioned, we use SEM for our statistical analysis. SEM is a method used to represent interactions between observed variables and others not observed or latent variables (Wu et al., 2015). SEM estimates the strength and significance of the relationships among the variables of the model.

After having determined descriptive statistics and correlations between observed variables, we have performed, multivariate normality tests to assess the underlying statistical assumptions of SEM estimation methods using PRELIS 2 program. Although our data did not manage to fulfil the assumption of multivariate normality, a small degree of deviation (skewness and kurtosis z values below |1.00|) did not invalidate the use of the maximum likelihood method with LISREL 8.80 software (Jöreskog, & Sörbom, 2006). Covariance errors between items were not implemented for the estimated model.

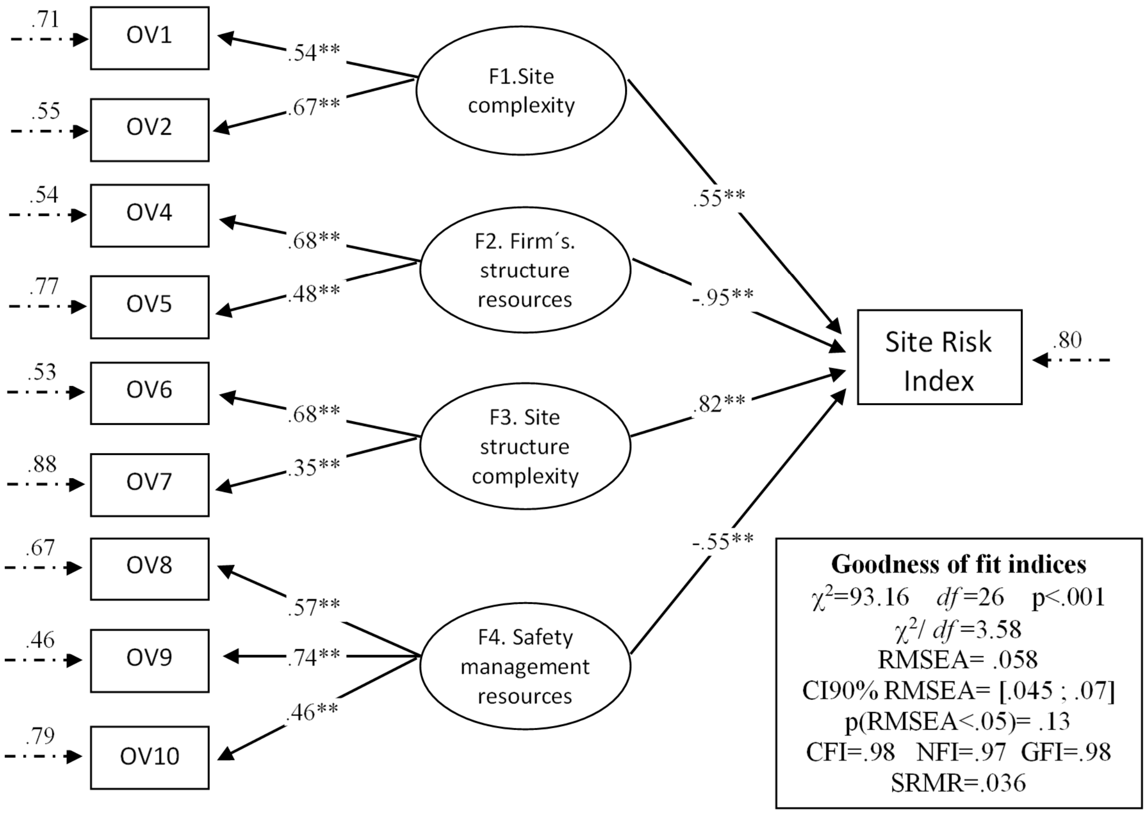
To assess overall fit of the model, χ^2, the relative/normed χ^2 to degrees of freedom (*df*) ratio, the Root Mean Square Error of Approximation (RMSEA) and its 90% Confidence Interval (with a p-value related to RMSEA<.05), the Standardized Root Mean Squared Residual (SRMR), the Comparative Fit Index (CFI), the Normed Fit Index (NFI) and the Goodness of Fit Index (GFI) were the used indices. A model can be considered to fit the data if c^2 is non-significant, χ^2/df <3, *RMSEA*<.05, *SRMR*<.08, and *CFI*, *NFI* and *GFI*≥.95 (Hu & Bentler, 1999; Schreiber, Stage, King, Nora, & Barlow, 2006). Finally, to test single parameters, the 5% significance criterion was adopted (i.e., t-value of parameters of 2.00).

2.6.2. - Structural model

As in any SEM analysis we have two different models: the measurement model and the structural model. As preliminary results showed that the observed variable OV3 (stage characteristics) was not significant. We removed this variable from the analysis and fitted the model (Figure 2).

Figure 2 shows the behaviour of our model with complete results of the SEM analysis coming from PRELIS 2 program. Path coefficients are the standardized versions of linear regression weights. According to this method, they can be used as informative of possible causal relationship between variables (Loehlin, 2004).

Figure 2. Structural equation model for organizational complexity and resources influence on risk level on construction sites.



Results for our model (Figure 2) showed an overall adequate fit to data (χ^2=93.16, *df* =26, p<.001), χ^2/df was lower than 5 and near than 3 (3.58), *RMSEA* stood slightly above at the cutoff of 0,5 for good fit (*RMSEA*=.058) with a *p*(*RMSEA*<.05)=.13 (CI90% *RMSEA*: .045; .07), both *CFI* (.98) and *GFI* (.98) were also indicative of good fit as *SRMR* (.036). Thus, except for the case of *RMSEA* all the other indices met the recommended limits to consider our model as good fitted. However, those *RMSEA* values below 0,8 can be considered as a not bad fit (Wu et al., 2015). We conclude that our model can be considered as acceptable. All path coefficients were statistically significant (p<.01).

2.7. - Discussion

The aim of the present research was to test the relations between organizational complexity and resources as potential predictors for risk site level. As we expected, site complexity had a positive direct effect on SRI (.55). Organisational structure resources had a very strong and negative direct effect on SRI (-.95). We also found a strong positive direct relationship between organisational design complexity and SRI (.82). Finally, safety management resources were directly and negatively related to SRI (.55).

Site complexity is a latent variable composed by complexity of project (OV1) and size of site (OV2). According to our results, site complexity had a positive direct effect on SRI. This result is consistent with the evidence found in previous researches (Fang et al., 2004; Forman, 2013; Hatipkarasulu, 2010; Hon et al., 2010; Manu et al., 2010). At the measurement model of our SEM, the latent variable of site complexity explained 29.29% of the variance of complexity of the project and 44.89% of the variance of size of site, which are the two observed variables that composed it. These two last variables represented the complexity measured through type of works, configuration and environment conditions (items of OV1), and size assessed by number of floors (OV2).

As we have reported in the previous section, the strongest effect on SRI is caused by the latent variable named firm´s structure resources. From our fitted model follows that this latent variable explains the 46.24% of the variance of promoter resources (OV4) which is based on only one item reflecting type of promoter’s resources and the 23.04% of the variance of contractor’s resources (OV5) conformed with the items of contractor’ type, role and site management structure. On one hand, the implied relationship between promoter (OV4) and SRI in our model is consistent with previous research where it has been found that type of promoter has relevant influence on H&S on site (Baxendale & Jones, 2000; Behm, 2005; Hinze et al., 2013; Ros et al., 2013; Xinyu et al., 2006). On the other hand, the specific relationship between contractor’s resources (OV5) and SRI is more controversial since previous research has not found concluding evidence although there is empirical evidence that relates firm´s structure with H&S in general terms (Camino López et al., 2008; Cheng et al., 2010; Holte et al., 2015; Pérez-Alonso et al., 2011). Wu et al. (2015, p.71) obtained different levels of safety performance with different types of constructions companies in China, specifically they found the best level of safety performance in Sino-Foreign Joint Ventures, followed by state owned enterprises and finally private enterprises with the lowest level of safety.

We also found a strong effect of latent variable site structure complexity on SRI (path coefficient of .82). This latent variable is formed by observed OV6 and OV7. The internal organization of the different companies on site (OV6) is composed by the type of contracting (one or more contractors), number of companies and level of subcontracting. Results imply that the site structure complexity explains the 46.24% of the variance of OV6. Previous research have found that more subcontracting leads to worst levels of safety (J. Hinze, Thurman, et al., 2013; López-Alonso et al., 2013; Manu et al., 2013; Swuste et al., 2012; Yung, 2009), our results are consistent with this evidence. There is no previous research to compare our results regarding the effects on risk either through the number of contractors or the number of companies.

The other observed variable OV7 (job planning and design) that loads on the latent factor of site structure complexity, contained the items of number of works, location of workers, total number of workers and ratio of own constructor's worker over the total number of workers. According to our results, the unobserved factor of complexity of site structure only explained the 12.25% of the variance of OV7. Among the items that compose OV7, only total number of workers on site was analysed in previous researches, where has been found a negative effect on H&S on sites, which is consistent with our results (Fang et al., 2004; López-Alonso et al., 2013).

Finally, the latent variable related with safety management resources is composed by coordination resources (i.e. designation of H&SC and his/her documented work) (OV8), preventive functions of the structure (OV9), and presence and appropriateness of the H&SP (OV10). Our results yielded that this latent variable explains the 32.49% of variance of OV8, the 54.76% of variance of OV9 and the 21.16% of variance of OV10. Our results are consistent with previous research referring to the preventive functions of the structure (Baxendale & Jones, 2000; Borys, 2012; D. P. Fang, Huang, et al., 2004; Jarvis & Tint, 2009; Manu et al., 2013). There is not previous research relating documented work of H&SC and the appropriateness of H&SP with levels of safety conditions on site. Despite preventive functions of the structure has the highest path coefficient in the relationship with safety management resources (.74), H&SC and H&SP have also a relevant path coefficients in this relationship, .57 and .46 respectively.

2.8. - Conclusions

Seams construction sector is typically one of the most high risk industries; there is a broad concern in finding approaches to address this problem. In order to control the risk at reasonable levels, one of the most prominent approaches consists in obtaining a set of leading indicators of safety conditions (i.e. predictors) before the accident event occurs (J. Hinze, Thurman, et al., 2013). Our study adopts this approach to analyse the relationship between four organizational variables, representing complexity and resources, and the risk level on site. Specifically, we have proposed that higher complexity in both the site and the site structure will have a negative impact on safety levels. We have also proposed that higher amount of resources behind the firm´s structure and supporting safety management activities will reduce risk. A structural equation model has been proposed to test these hypotheses and we have fitted the model using data collected during 957 direct inspections on construction sites.

As a result of our research the following general conclusions can be drawn. In first place, we found that our four OV (site complexity, firm´s structure resources, site structure complexity and safety management resources) have direct and relevant impact on an index reflecting level of risk (SRI) as we were expecting. The relevancy of those findings is that the OV considered can be used as predictor of risk with important implications as we propose below.

In second place, our analyses revealed that all our relationships (hypotheses) were statistically significant at .01 level and with the expected sings. We have obtained that the most important factor to explain the risk on sites is the firm´s structure resources (see F2 in Figure 2, section 5.3) with a path coefficient of -.95. We have also found that the site structure complexity (F3) has also an important positive and direct effect on risk, path coefficient of .82. Weaker effects on site risk were found for the factor of site complexity (F1), with a positive path coefficient of .55 and safety management resources (F4) having a negative path coefficient of -.55.

Our results showed that the risk on site, if we look at the organizational factor proposed, is mainly affected by firm structure (F2) and site structure complexity (F3), and the most relevant variables within those two factors were promoters' and constructors' resources (OV4 and OV5) and organizational structure (OV6). Some important implications can be derived from these findings. On one hand, a reinforcement of the promoter role, having more professional agents endowed with more resources, will increase the involvement with H&S issues. This is in line with the study reported in Sparer & Dennerlein (2013), where an important promoter developed an innovative campaign to improve safety, which is really unusual in the construction sector. Regarding constructor's resources (OV5) our results suggest that improving the constructors' resources, reinforcing constructor's role on leading the works on sites and strengthening site management structure might improve safety on site. All those goals can be achieved having more professionalised companies with more stable structures and well trained and informed workforce about H&S issues. It is equally important to assure an active presence and control on works by contractors and the assignment of the appropriate human resources to be explicitly present on site.

On the other hand, since organizational structure variable (OV6) is composed by type of contracting, number of companies and level of subcontracting which affect negatively the risk level on site, might be necessary to consider whether construction normative and regulations should address these questions. Measures such as limiting the level of subcontracting are already implemented, but other interventions which are not currently undertaken might be, for example, limiting the number of contractors or the total number of companies on site.

Regarding safety management resources (F4), the most remarkable effect found is for preventive functions (OV9) in comparison to the effects of the other two variables. We conclude with the importance of assume preventive functions in relation to end safety conditions. Connecting with results obtained for factor F2 (firm's structure resources), seems that in order to have acceptable levels of safety would be not enough simply having the figure of a foreman or manager, but whether they are really or not assuming the preventive functions. One direct implication can be derived is that is as important have the site manager or foreman as they assume and develop preventive functions.

The main theoretical limitation of the present research is that we have addressed only one side of the problem to explain the level of risk, let us say the life conditions on sites, ignoring the side determined by workers behaviours (attitudes, climate, culture, etc.). We think that future models intended to explain risk and to propose safety interventions should consider jointly both faces of the same coin.

Other limitation of our study is that the majority of the sites in our sample are small and medium local constructions firms with low levels of resources. Of course, this supposes a limitation to generalise our results to the whole sector or other geographical regions.

Despite these limitations this research has relevant contributions. In first place, we have used field data from a large number of sites collected directly from the work scenarios while we were developing safety inspections. In second place, we have found evidence supporting that organizational factors, as complexity and resources, are good predictors of level of risk. Our model of organisational latent factors explained 20.00% of the variance of SRI. This result is an important issue to develop tools aimed to obtain leading site indicators as well as planning any future organization and resources of any site. It is an important argument for managers and contracting companies to implement some of the improvements considered, taking in account the relationships with site risk, and finally, with the expected results on accidents rates. Other practical implications of present study is to propose interventions and design safety campaigns to direct the adequate actions towards those organizational dimensions.

3. - Occupational risks, accidents on sites and economic performance of construction firms.

3.1. - Abstract

This paper examines the relationships among site risk, accident rate and firm economic performance in construction industry. We first assess safety levels on site using a specific tool we have developed, CONSRAT. We have examined during 6 years (2004-2009) 502 construction sites of 272 Spanish companies in Mallorca. We built a panel data with these safety assessments, the firm financial performance and the accident rates.

Our general hypotheses are that risk on site have an effect on accident rates and the accident rates affects firm economic performance. On one hand, we obtain a significant positive linear relationship between site risk and accident rate. On the other hand, we find a significant quadratic relationship (inverted U shape) between accident rate and economic firm performance. Our empirical evidences suggest a complex relationship between those variables. Specifically, for a low range of accidents we can observe that company profitability increases while accident rate grows up, arriving to a tipping point from which more additional accidents will reduce the company profitability.

These results suggest that we need policies to control accident rates, since the total cost of accidents by itself might not be enough to influence firms to invest in safety prevention.

Keywords: site risk, construction site, accident rates, economic performance.

3.2. - Introduction

There is an enormous amount of academic work studying which construction site conditions are prevalent when the accident occurs. This literature is reactive in nature as it is aimed to explain probable risk conditions on sites involving accident event reports (Camino López et al., 2011; Cheng et al., 2012; Cheng et al., 2010; Conte et al., 2011; J. W. Hinze & Teizer, 2011; Liao & Perng, 2008; López Arquillos et al., 2012; McVittie et al., 1997; Nishikitani & Yano, 2008). Another important research line proposes methods to conduct in depth analysis of occupational accidents, although only large companies seem are using these methods (Kirsten Jørgensen, 2016). Among them we have the “Storybuilder” (Bellamy et al., 2007) in the framework of Worm project, where over 20.000 serious accidents were analysed, jointly with their barriers, and 64 types of hazards were summarised (Ale, 2006; Bellamy, 2010).

Other line of research within health and safety (H&S) has adopted a more preventive approach as it tries to avoid accidents through risk assessment based mainly on site conditions (Memarian & Mitropoulos, 2013; Cambraia et al., 2010; Wu et al., 2010; Yang et al., 2012). However, there is a limited number of studies trying to model the relationship between risk conditions on site and the likelihood of accidents. One example is the study by J. Hinze et al. (2013) where the authors analysed which leading indicators can be utilized to assess safety performance (e.g. works, supervisors, managers, owners, and designers, all them at jobsite). Another example, Sparer & Dennerlein (2013) developed a software to identify sites with high accident risks using leading indicators to measure work conditions that can affect the risks.

More attention to construction tasks is necessary as studies at task level only represent the 2.28% of all research on H&S in the construction industry (Zhou et al., 2015). There is a lack of field risk exposition measurements on sites (Swuste et al., 2012) because most of the research tend to be epidemiological and mainly focused on accidents.

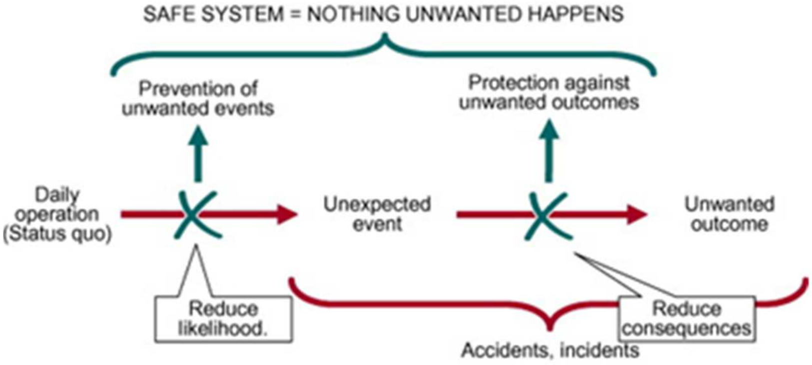
On another level, H&S has been identified as one of the issues that are relevant for company results, competitive advantage and management performance (Teo & Ling, 2006; Argilés-Bosch et al., 2014; Rechenthin, 2004). Most of the research connecting these issues in construction industry has been theoretical. Following Chalos (1992) theoretical framework of cost of safety (COS model), many scholars have analysed, two well-known dimensions of H&S cost, prevention and accidents costs (Cheng et al., 2010; Cheng, Lin, et al., 2010; Feng et al., 2015; Gurcanli et al., 2015; Harshbarger, 2001; HSE, 2015; Ibarrondo-Dávila et al., 2015; Labelle, 2000). Despite the cost of H&S has been studied in some depth, it is surprising the absence of empirical works trying to understand which is the relationship between those costs and the economic benefit of the firms. The cost of occupational accidents is increasing, and therefore raising safety levels would generate a win-win solution for all parts, including the employees, the firm as well as society (EUROSTAT, 2004; Gavious, Mizrahi, Shani, & Minchuk, 2009; Kirsten Jørgensen, 2016). Despite this reasonable relationship, to the best of our knowledge, there is just a one single published paper dealing with this issue (Argilés-Bosch et al., 2014). Particularly, these authors found a linear negative relationship between accident rates and firm financial performance one year ahead. Although, this is a very interesting result it may fail to explain a potential more complex relationship between those variables. Our research question is directed to this point: Is it possible a non-linear relationship between benefits and accidents. Can firms support accident costs without affecting their financial performance? As we will see, our empirical research provides evidences regarding the relationships between risk-accidents on the one hand and between accidents-firm performance on the other hand.

The structure of this manuscript is as follow: 1) A review of the literature and the statement of our hypotheses; 2) A description of the empirical methodology (sample, data collection and empirical design); 3) A report of the results; 4) A discussion of most relevant findings along with some conclusions; 5) A set of limitations of our study and some lines for future research.

3.3. - Literature review and hypotheses statement

There is an extensive body of theoretical models connecting risk with accidents. The traditional “bowtie metaphor” from Visser (1998) can be considered as the one of the first theoretical model of the process of H&S management and the consequences of risks. Following this metaphor, existing uncontrollable hazards converge in the so called “central event” which in turn may evolve and diverge into different risks causing potential damages or accidents. The first role of management in such a scenarios is to interpose some barriers to prevent the conversion of hazards into risks, and the second is to build some protections to prevent risks becoming accidents. Figure 1 shows a reinterpretation of the model by Hollnagel (2008) analysing the two dimensions of risk management (i.e. prevention and protection).

Figure 1. Safety model: prevention and protection.



Source: (Hollnagel, 2008)

Acording to Hollnagel´s (2008) model, once we have the safe system operating, one of its important consequences is the decreasing of accident rates or, in the best possible situation, that "nothing unwanted happens".

The problematic issue here is that, despite the proposals of these models, the relationship risk-accident is not always contingent because not all risk expositions finally end in accidents and, alternatively, some good safety systems can have some accident. In fact, most of the risk-exposition does not end in accident, or in other words, we do not have as many accidents as it might be expected probably because workers are able to control most of risk situations (Sundström-Frisk, 1985). As Khanzode et al. (2012) concluded, there is a gap in the literature because the study of risk assessment is disconnected of the causality model of accidents that have been proposed. Although this gap is important at the theoretical level, it is more salient at the level of empirical and field research. There is a clear scarcity of exposition measures on site, and there is also a need to identify which main events are related with accidents (Swuste et al., 2012). Only a limited number of empirical researches connect risk conditions on site with accidents results. Most of these studies are contextualised in the assessment of the effectiveness of specific and very focused safety campaigns (Hale et al., 2010; Kines et al., 2010; Laitinen & Päivärinta, 2010; Laitinen & Ruohomäki, 1996; Spangenberg et al., 2002) or in the assessment of the effectiveness of implemented management systems (Yoon et al., 2013). We have only found one study that considers the level of hazard of a project as a moderator variable over the relationship between accidents rates and the total cost of accidents (Feng et al., 2015). From the literature it can be concluded that there is a need to generate more knowledge about the empirical interaction between risk conditions and accidents. Consequently, the first hypothesis is aimed to test whether or not an increasing relationship exists between risk levels and accident rates when you consider a relatively long spam of years:

H1. High levels of risk on sites have a positive effect on accidents rates.

Managers seem to ignore the economic consequences of unsafe practices in the workplace (Harshbarger, 2001). Since they don't have accurate estimates of the economic impact of accidents, they cannot consequently assess which is the economic contribution of the function H&S management, and consequently, there seem to be low awareness of its strategic value (Labelle, 2000). In order to keep companies being competitive, many contractors try to control short term total operation costs by executing only basic safety measures during construction project implementation (Cheng, et al., 2010). It is important to prioritise safety, but other demands as finance, client, production and deadlines change these priorities (Kirsten Jørgensen, 2016). Due to the uncertainty of overall H&S costs and the daily demands, the companies do not apply several protection measures, reducing direct H&S costs (i.e. cost of prevention and protection measures) but ignoring the amount of indirect H&S costs (i.e. cost of accidents) they will have to afford when accidents occur. H&S costs, both direct and indirect, do exist and they are high (Ibarrondo-Dávila et al., 2015). Companies do not have appropriate accounting systems to estimate these costs. Although, there is not a standard method for estimating direct costs. Gurcanli et al. (2015) have calculated that the cost of safety measures represents a 1.9% of a residential building project budget.

Focusing on accidents, they affect costs in many ways at the level of the individuals, the company or the Public Administration: healthcare costs, production losses, delays, lost working days, penalties, etc. (HSE, 2015). In his historical work, Heinrich (1927, 1941) classified accident costs into direct and indirect, concluding that even when the amount of direct cost of accidents are important, indirect costs can be even much higher than direct ones. Direct costs of accidents refers to the expenses directly related with injuries and fatalities, while indirect cost of accidents include productivity losses, disruption in schedules, delays in completion dates, fines and legal expenses, damage in organization image, etc. (Ibarrondo-Dávila et al., 2015; Feng et al., 2015). The complex relationship between the occurrence of accidents and their cost cannot be explained by one single variable (López-Alonso et al., 2013). In this line, (Feng et al., 2015) described up to 13 possible components of indirect costs of accidents based on previous literature review. Moreover, these authors concluded that workplace accident costs of building projects are influenced by accident rates, project hazard level, project size, company size and the involvement of sub-contractors. Feng et al. (2015) have reported that total accidents cost of building projects accounts for 0.25% of total contract sum. Another interesting finding of this research is that the positive effect of accidents rates on total accident costs is moderated by project hazard level, as we have already mentioned above. Hallowell (2011) reported that construction injuries impact firm financial performance by increasing total cost up to 15% in new non-residential projects. Therefore, in the literature there is some results supporting the hypothesis that accidents may have a negative impact on economic results of construction companies via increasing organizational costs.

There is a complex structure of accidents costs with different types and not obvious relationships among them, which makes more complex to stablish a relationship between accident and economic performance of the firms. We have found only one recent empirical study where the incidence of accidents on firm financial performance is estimated. Using panel data for a period of six years (from 1998 to 2003) and a sample of 99 construction firms, Argilés-Bosch et al. (2014) have found evidence of a negative relationship between accidents in one year and firm financial performance one year ahead. In our research we want to check whether or not this hypothesis and results hold for the period of time we are considering and our sample. Therefore, our second hypothesis is stated as:

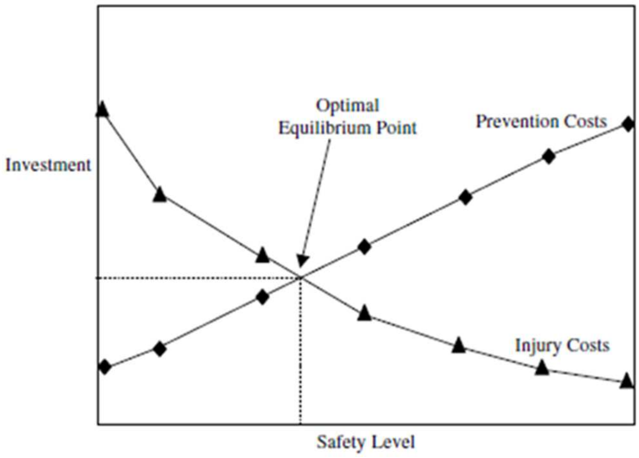
H2. Work accidents have a negative effect on firm financial performance.

Up to this point we have reviewed two kinds of costs affecting safety management, accident costs and prevention/protection costs (Cheng et al., 2010; Gurcanli et al., 2015; Ibarrondo-Dávila et al., 2015). Additionally, we have also reviewed the classification of accidents cost as direct and indirect. However, it has been proposed that there is an interaction among preventive costs and accident costs. Specifically, the theory of indirect costs of accidents (Brodyet al., 1990) proposes that increases in indirect costs of accidents tend to generate rises in the investment to improve the safety on building sites. As it can be seen, our study is focused on the economic side of the safety behaviour of construction firms. Of course, economic aspects are not the unique arguments to explain this behaviour, but all remaining and important aspects are out of the scope fo our study.

Focusing on economic arguments, the central issue for analysing how H&S management relates with firm financial performance results is the joint consideration of both H&S direct costs (safety measures, prevention) and H&S indirect costs (accidents, healing or remedial). Safety measures are a cost that researches and practitioners classify like an inversion (Fernández-Muñiz, Montes-Peón, & Vázquez-Ordás, 2009; Ibarrondo-Dávila et al., 2015). Of course, there are an investment precisely because in the adequate level safety measures reduce indirect costs caused by accidents or other personal damages, and they can generate other gains due to organizational effectiveness. Related exclusively with safety investment at construction building projects, Feng (2015) has developed some models for helping contractors to make decisions regarding the amount of financial resources they need to invest in safety. This research have changed the approach of the of H&S economic issues from a mainly reactive perspective to a more proactive approach, by addressing the problem of determining efficient safety investments.

Although any risk management system can reduce accident rates and also injuries costs, Hallowell (2011) pointed out that these systems also suppose a cost for the companies. In the safety management, a company face two types of costs that move in opposite direction, cost of accidents (decreasing with safety) and cost of prevention/protection (increasing with safety). Therefore, it is important to know how to evaluate the cost-benefit of investments in safety management. Hallowell (2011) concluded that the optimal investment strategy depends on the frequency and costs of accidents and the organization's attitude toward tolerance to risk, among others factors. One important conceptual model to approximate cost-benefit analysis of safety is the cost of safety (COS) model (Chalos, 1992), which is illustrated in Figure 2. Under the premise that more preventive actions tend to reduce the number of accidents and their associated costs, COS model defines that the optimal level of safety investment is that when the cost of preventive measures equals the cost of accidents. This theory assumes than some level of risk is inherent to the main work processes and that getting down this risk could be economical inviable (M. Behm, Veltri, & Kleinorge, 2004; Manuele & Main, 2002). Therefore, high and low levels of safety investment may harm firm economic performance, via increasing total cost derived from the safety management.

Figure. 2. The model of cost of safety. (COS).



Source: (Hollnagel, 2008). COS model adapted from Chalos (1992) and Behm et al. (2004)

Other authors have analysed the factors influencing safety investment decisions by the government and the firms from an opportunity cost perspective (Ma et al., 2016). These authors consider that optimal safety investment decisions are those that minimize its total opportunity cost. This opportunity cost would be composed by "shortage costs" due to the occurrence of accidents (defined as direct accidents costs for firms and government costs from stablishing wrong regulations) and excess cost due to investing more than required for accident prevention.1

The assumption in COS model and Ma et al.'s (2016) study is that there is a quadratic relationship between safety level and the total cost of H&S. Due to the non-contingency of accidents and safety levels, the COS model cannot be directly translated into a model that explains number of accidents with economic results of firms. Although this is true, the underlying ideas of COS model and Ma et al.'s, (2016) make us to think that the relationship between the economic firm performance and the accident rate might not be the monotonous linear function. Besides the obvious cases with high accident rates and low levels of safety, it is also possible to find firms with no accident rates and very poor safety conditions. For the later firms, a particular evolution of their net benefits can be expected. When accidents appear, cost starts to raise and will offset the savings generated because of low safety levels. Therefore, we are arguing a quadratic relationship between the accident rate and the economic firm performance instead lineal. This quadratic relationship would also be more consistent with the U-shape of total H&S cost proposed by COS model. According to our arguments, we propose the following third hypothesis to be tested in this research:

> **H3. There is a quadratic relationship between accidents and firm financial performance. For low levels of accidents there is an increasing positive effect on firm financial performance while for large levels of accidents there is an increasing negative effect on firm performance.**

---

[1] Ma et al. (2016) interestingly discuss that the compulsory safety investment established by government, can force the firms to invest more in safety measures than the required level to have a zero rate of accidents (what they call as the needed safety investment for possible accidents prevention). In other words, there may be redundant investment that would imply cost due to inefficient decisions. In the case of China, the authors concluded that there is a lower than needed government and firms safety investment because of the ineffective features of the whole administrative system and the existence of a bribery culture, that finally translate into a high accident rate.

H3a. Firm financial performance varies positively with accidents rates.

H3b. Firm financial performance varies negatively with the square of accidents rates.

3.4. - Methods and materials

3.4.1. - Empirical design

According to our hypotheses we propose to test three models. Following we define all variables and the specification for the models.

In order to regress the accident rate (*ACCRATE*) on the site risk Index (*SRI*), we have first obtained the *ACCRATE* as the proportion of accidents over of total number of workers in the firm. *SRI* is the average of 10 risk variables, measured on site with CONSRAT (Construction site risk assessment tool) we have created to measure site risk in a broader research project. More levels of this variable means more risk on site (low compliance of H&S plan, bad conditions of order, tidiness or access, low or inefficient protections, high levels of falls of height or other risks, etc.). To regress *ACCRATE* on *SRI*, we use a control variable that represents the organizational design complexity (*ORGDES*). This variable tries to capture different elements related with site organizational structure and planning, related previously with H&S on site (Fang, Huang, et al., 2004; Hinze et al., 2013; López-Alonso, et al., 2013; Manu el al., 2013; Swuste et al., 2012; Yung, 2009). *ORGDES* is computed with the information from CONSRAT and we have used it in previous empirical studies. A higher value of *ORGDES* means more complexity on site design (more companies, more contractors, more levels of subcontracting, more works, etc.). We expect a positive relationship between *ORGDES* and *ACCRATE*.

In our second and third model we propose to connect firm financial performance as the dependent variable with accident rates as the independent variable using two different specifications, linear and quadratic. In both models we use ROA as a firm profitability measure because is the most common used indicator of firm financial performance in the literature (Tan & Wang, 2010) and adequate for samples such as ours which are usually composed by non-listed firms (Argilés-Bosch et al., 2014). ROA “is the ratio of income before leverage to total assets in percent, indicating firm profitability before leverage relative to its size” (Argilés-Bosch et al., 2014). Following these authors and some others (Bandyopadhyay et al., 2010; Cheng, 2005), past profitability is partially explained by past firm management and characteristics, as it also an explicative factor in part of future profitability. Therefore, we also assume that present firm profitability depends on its profitability in previous period and we control for it in our model. Additionally, Argilés-Bosch et al. (2014) pointed out that profitability also depends on management decisions in the same year which impact organizational efficiency. A common variable used in business literature to capture efficiency is asset turnover (the ratio of firm sales to total assets) (Fairfield & Yohn, 2001). As Argilés-Bosch et al. (2014) did, we have included in our model a variable to control for current firm efficiency change in the period due to present management decisions. This variable (CHASSETURN) is calculated as the difference between a company asset turnover in a given year and in the previous year, relative to asset turnover in the previous year. i.e. is the perceptual change in asset turnover in a given period. We expect a positive relationship with ROA.

All these economic variables are also influenced by market conditions and political decisions among others factors. However, the specific consideration of all these variables are beyond the scope of our study. As in Argilés-Bosch et al. (2014), all those potential explicative factors of ROA, which are not explicitly included in our models, will show their estimated impact either in the lagged ROA variable, the dummies of year variables and also in the error term of our models which, in turn, will determined the percentage of the variance that our models explain.

According to our hypothesis 1, 2 and 3, their corresponding model specifications are as follow:

H1: $ACCRATE_{i,t} = ß_0 + ß_2 \,.\, SRI_{i,t} + ß_3 \,.\, ORGDES_{i,t} + \varepsilon_{i,t}$ (Model 1)

H2: $ROA_{i,t} = ß_0 + ß_1 \,.\, ROA_{t-1} + ß_2 \,.\, ACCRATE_t + ß_3 \,.\, CHASSETURN + \varepsilon_{i,t}$ (Model 2)

H3: $ROA_{i,t} = ß_0 + ß_1 \,.\, ROA_{i,t-1} + ß_2 \,.\, ACCRATE_{i,t} + ß_3 \,.\, (ACCRATE_{i,t})^2 + ß_4 \,.\, CHASSETURN + \varepsilon_{i,t}$ (Model 3)

3.4.2. - Variables, sample and data collection

Variables

As we have mentioned *SRI* and *ORGDES* were obtained through CONSRAT. Our tool serves to record responses and assessments on sites related with H&S as well as organizational issues. It contains 97 questions or items to conform 10 variables related to risk, and 10 related to different organizational variables. Each item of CONSRAT has a rating with specific criteria and scoring to allow aggregation with others items. The aggregation rules among item to build risk as well organizational variables are object of previous research (see Paper 1, chapter 1).

SRI ranges from 0 (representing no risk) to 1 (signalling maximum risk). It is composed by: Health and safety plan accomplishment (RV1); General condition of the construction work (RV2) (enclosures, circulations, tidiness, cleanliness and illumination, signalling and the electrical system); General conditions of the collective protections (RV3); Specific conditions of phase access (RV4); Falls from height assessment (RV5); Up to 11 other risks identification (RV6); Process evaluation (RV7); Collective (RV8) and Individual (RV9) protections assessment at main stage; Auxiliary resources and machinery adequacy and assessment (RV10).

ORGDES ranges from 0 (representing no complexity or resources) to 1 (signalling maximum complexity or resources). It is composed by: Internal organization structure (OV1) and Job planning and design (OV2). It has been built using a panel of experts, using different weights of the two variables and of all their internal items. See Appendix A-3 for further information.

Sample

We collected information regarding live conditions visiting a total of 957 sites, mostly building constructions, in Mallorca (Balearic Islands), pertaining to a total of 627 companies. All sites in our sample were selected following random criteria and were collected from 2004 to 2009.

We crossed our initial sample with data on accident rates from Balearic Islands Labour Authority and SABI data base of Bureau van Dijk. As a consequence, we rejected companies with headquarters not located at this region or with not available information in SABI. Table 1 describes the final sample taking in account these issues.

Our sample is composed by all types of firms, including firms with no accidents and firms with any type of accidents (minor injuries, serious injuries and fatalities) without prioritizing by severity. We consider indicative of some preventive problem any kind of accident independently of its seriousness (Kirsten Jørgensen, 2011). Prioritizing the severity could cause a loss of preventive information of a company (Bellamy, 2015; Khanzode et al., 2012)

Table 1. Total sample of construction sites and companies.

Total sample	
Firms	Work sites
272	502

3.5. - Results

Table 2 reports the information we have collected using our CONSRAT (*SRI*), SABI database (*ROA*, number of workers) and Labour Authority records (number of accidents, Official and sample Incidence Rate). Sample incidence rate is obtained dividing number of accidents with number of workers for each year of sample firms. Average *ROA* and *SRI* is obtained from each available firm data from each year using the different sources mentioned before. Incidence Rate is the official data published by Labour Authority for Balearic Islands.

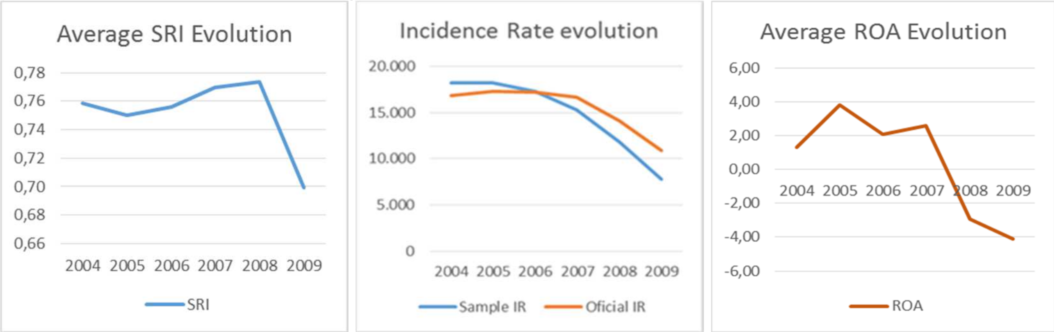
Table 2. Description of sample composition per year and some relevant data from our sample of 272 firms.

	2004	2005	2006	2007	2008	2009	Total
Number of firms with *SRI* assessments	91	68	62	77	44	13	355
Number of *ROA* data	220	236	243	224	215	204	1.342
Number of accidents	925	977	1.047	972	699	385	5.005
Number of workers	5.088	5.363	6.044	6.364	5.929	4.958	33.746
							Mean
Sample Incidence Rate[1]	18.180,03	18.217,42	17.322,96	15.273,41	11.789,51	7.765,23	14.831,39
Official Incidence Rate[2]	16.829,03	17.315,00	17.156,00	16.653,00	14.128,10	10.865,50	15.491,10
Average *ROA*	1,29	3,81	2,06	2,60	-2,91	-4,12	0,60
Average *SRI*	0,76	0,75	0,76	0,77	0,77	0,70	0,76

[1]Number of accidents divided into number of workers and multiplied by 100.00. [2]Number of accidents per 100.000 workers of Official data from construction sector in Balearic Islands, i.e. the whole population. (Source: Conselleria de Trabajo, CAIB and Ministerio de Empleo y Seguridad Social).

As you can see in Table 2, the total number of firms with SRI assessments (355) is different from the total number firms (272) in Table 1, as we have 147 firms' sites with more than one site assessed. We approximate the annual firm´s SRI as the average of the SRIs' sites assessed this year.

Figure 3. Graphics of average of *SRI*, *ACCRATE* (official and sample) and *ROA* for sample firms



SRI is the index of risk on site; *Incidence Rate* is the number of accidents per 100.000 worker; *ROA* is the percent of return on assets.

Figure 3 shows the evolution of some of our sample variables. As we can see the crisis of the Spanish construction sector is evidenced in the evolution of the average *ROA*. But *ROA* captures also a set of variables including firm managerial decisions in present and past years (Argilés-Bosch et al., 2014).

Figure 4 shows the classification of the sites in our sample according to their observed levels of *SRI*. "Correct" means general well compliance of all variables. All barriers are well installed, reliable, and independent for the workers that can used it. Low levels of risk and coincide of risks, general good conditions. "Acceptable" means appropriate, without critical failures. There can be some minor failures, but in overall a compliance exists with the needed conditions, the low level of the risks, the coincidence of them and quality and installation of barriers with possible problems but never compromising its utility. And "Unacceptable" means deficient, with high risk, critical failures on protections or lack of them, they are significant and could affect the barriers, the installation, the user or other persons (for further details see paper 1, chapter 1). Table 3 reports some descriptive statistics of the relevant variables included in our models, and Table 4 contains the corresponding Pearson correlation matrix among dependent, independent and control variables present in our models (see section 3.1).

Figure 4. Graphic circular of SRI classification of sample

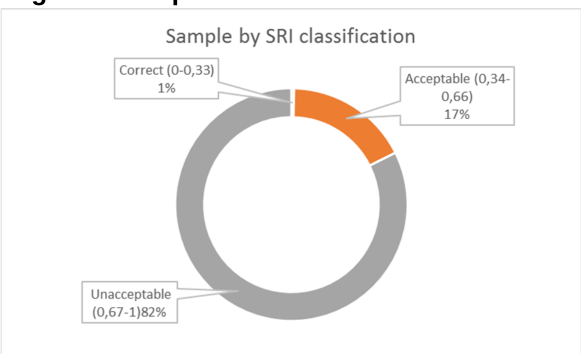


Table 3. Descriptive statistics.

	Mean	Std. Err.	[95% Conf. Interval]		Number obs.
SRI	0,76	0,0069479	0,7445609	0,7718898	355
ORGDES	32,62	0,7551857	31,13479	34,10516	355
ROA	0,60	0,6480713	-0,6739519	1,868736	1342
ACCRATE	0,13	0,0053965	0,1231916	0,1443608	1671
CHASSETURN	0,50	0,2031671	0,1061582	0,9033379	1239

SRI is the index of risk on site; *ORGDES* is a level of complexity of site organizational design; *ROA* is the percent of return on assets; *ACCRATE is the rate of workers injured with respect to the total firm workers*; *CHASSETURN* is the perceptual change rate in asset turnover in a given period.

Table 4. Pearson correlations between our model variables

	SRI	*ORGDES*	*ROA*	*ACCRATE*	*ACCRATE*^{2}	*CHASSETURN*	*ROA*$_{t-1}$	*ACCRATE*$_{t-1}$
SRI	1.00							
ORGDES	-0.15***	1.00						
ROA	-0.04	0.10*	1.00					
ACCRATE	0.09*	*0.09**	0.07***	1.00				
ACCRATE^2	0.10*	*0.05*	0.03	0.83***	1.00			
CHASSETUR	0.06	*-0.03*	0.06**	-0.01	0.00	1.00		
ROA$_{t-1}$	-0.07	*-0.007*	0.21***	-0.05*	-0.07***	-0.03	1.00	
ACCRATE$_{t-1}$	0.09	*0.03*	0.03	0.28***	0.20***	-0.01	0.04	1.00

SRI is index of risk on site; *ORGDES* is a level of complexity of site organizational design; *ROA* is the percent of return on assets; *ACCRATE* is the rate of workers injured with respect to the total firm workers; *ACCRATE*^{2} is the quadratic term of *ACCRATE*; *CHASSETURN is the perceptual change rate in asset turnover in a given period.*
* Significance level: $p < 0.1$.
** Significance level: $p < 0.05$.
*** Significance level: $p < 0.01$.

As table 4 shows, collinearity does not seem to affect the estimations of our models as it can be deduced by the low levels of Pearson correlations between the independent variables of our models. In the context of our Model (1), we have found a significant correlation between our independent variable *SRI* and the control variable *ORGDES* (-0.1456, p<0.01), suggesting a possible problem of collinearity between these variables. After conducting a test for collinearity using variance inflation factor (VIF command in STATA) we rejected that collinearity is a problem in our model as we obtained all values to be close to 1, which are far below from 10.

In relation to the other two models (2 and 3), a significant correlation between *ROA* (profitability) and *CHASSETURN* (efficiency) is found, (0.0610, p<0.05). As Argilés-Bosch et al. (2014) explained, though this correlation is positive as one would expect, its low magnitude might be caused because *CHASSETURN* contains information just for one year (it is a year change rate) and *ROA* includes information regarding managerial decisions of both current and past years. We have also found significant negative correlations between *ROA*$_{t-1}$ and both *ACCRATE* (-0.0513, p<0.1) and *ACCRATE*^{2} (-0.0725, p<0.01) but they are very small. This suggests that those firms with less past profitability are associated with a higher current accident rate. The results after using VIF test did not signal any problem with multicollinearity as all variables VIF values were below 3.5.

To test our hypotheses, we have estimated our models using several methods for panel data estimation (pooled, fixed effects and random effects estimators). Additionally, we have added some dummy year variables to explore for time specific effects. In order to control the possible existence of heteroskedasticity, all models were estimated using robust methods. Additionally, we have run Hausman test (Hsiao, 2014) in order to verify which estimation method, random versus fixed effects, better adjusted our data. For the model (1) the Hausman test does not reject the null hypothesis of no correlation between individual effects and the independent variable, therefore individual effects are uncorrelated with the regressors and the random effects estimator is consistent and efficient. For the models (2) and (3) Hausman test rejects the null hypothesis of no correlation between individual effects and the independent variable which implies that individual effects are correlated with the regressors and the fixed effects estimator seems to be more consistent and efficient than the random estimator.

Table 5 shows the results for model (1). The columns 1 to 3 contain the baseline model including only the control variables. The columns 4 to 6 add the explanatory variable, and finally the columns 7 to 9 show the complete model that includes the year dummy variables. .As we can see, the coefficients of our explanatory variable, SRI, are positive and significant *p*<0.05 for pooled and random effects estimators, either with or without dummies of years, while in fixed effects estimators the coefficient is not significant without adding the year dummy variables and significant at p<0.1 with dummy variables. Control variables have in the complete model a similar behaviour compared to the other models. Hausman test (9.03) is not significant at p<0.1 with seven degrees of freedom, it does not reject the null hypothesis of no correlation between individual effects and the explanatory variable, which means that random effects estimator are more efficient and consistent than the fixed effects ones.

INSERT TABLE 5 ABOUT HERE

As it can be seen in Table 5 the pooled and random estimations of parameters for 2008 and 2009 dummy variables are significant at p<0.05 and the explanatory variable, SRI, remains significant at p<0.05 when we add year dummies. In order to have an approximation of the influence of those years, we have replicated the estimation of the model (1) shortening the panel to the years 2004 to 2007. Results are shown in Table 6.

INSERT TABLE 6 ABOUT HERE

Although these results must be taken with caution because of the short length of the panel, we can see in Table 6 that significant effects of *SRI* on *ACCRATE* still hold, while the estimations of the effect for year dummies are not significant for pooled and random estimations. Pooled and random effects are still more efficient and consistent estimations, and the explanatory variable, *SRI*, has a significant estimated effect (p>0.01) on accident rates with or without dummy of years. The different estimations methods show significant goodness of fit.

Following a similar estimation strategy, Table 7 shows the estimations results for model (2) using the three different estimation methods. As we have stated above, this model (2) propose to test the relationship between accident rate (*ACCRATE*) and firm financial performance (*ROA*) on construction sector. Columns 1 to 3 of results contain the baseline model including only the control variables. Columns 4 to 6 add the explanatory variable, and finally columns 7 to9 show the complete model that includes the year dummy variables.

Regarding our explanatory variable, *ACCRATE*, it can be seen in Table 7 that we have obtained a positive and significant effect on *ROA* for pooled and random effects estimations (p>0.05) and for fixed effects estimation (p>0.01) (model specifications without year dummies, see result columns 4 - 6). These significant results for *ACCRATE* are not maintained when we add the year dummies into our model specification (see result columns 7 to 9). For that complete model specification, we can see that years 2008 and 2009 have a negative and significant effect on *ROA* (p>0.01) for all the three estimation methods. Although results are not reported here, we did not find any significant effect between accidents rate on previous year and *ROA* on current year.

INSERT TABLE 7 ABOUT HERE

As we have mentioned previously, for this model (2) the Hausman test (176.00) is significant at $p<0.01$ with eight degrees of freedom, therefore fixed effects estimators are more efficient and consistent than random effects ones. As it can be seen in Table 7, the estimations in model (2) presented a significant goodness of fit ($p<0.01$)

Similarly to model (1) estimation, we observe that 2008 and 2009 dummies have a significant negative effect on *ROA* ($p<0.01$) in model (2). However, when year dummies enter into the model (2) specification, the significance of our explanatory variable disappears. Following the same reasons as in model (1) estimation strategy, we have also tested the whole model (2) for a restricted period of years of our panel data (i.e. eliminating 2008 and 2009). Although we don't report here the results of this restricted model, the explanatory variable was not significant at $p<0.1$ in any model specification, neither the year dummies.

Table 8 reports model (3) estimation results without the baseline model as is the same that in model (2) (see Table 7). For pooled and random effects estimations in the two specifications with and without year dummy variables, our control variables ROA_{t-1} and *CHASSETURN* are significant ($p<0.01$) and positive as expected, however for fixed effects estimate, ROA_{t-1} loses the significance. Regarding our explanatory variable, *ACCRATE*, the linear term is positive and significant ($p<0.01$) and the quadratic term is negative and significant ($p<0.01$) for all the estimation models without the year dummies (see results columns 1 to 3 in Table 8). These results are consistent with our hypothesis H3. When we introduce into the model (3) all year dummies, we can see that the estimated results for the explanatory variable change. Specifically, the significance of the linear effect of *ACCRATE* on *ROA* only holds for the random effects estimations at $p<0.1$, while the quadratic term remains significant at $p<0.05$ for the random effect estimation and at $p<0.01$ for the pooled and fixed effect estimations. Notwithstanding, all the estimated effects for *ACCRATE* and $ACCRATE^2$ are in the direction we propose in our hypothesis H3. As we have mentioned before, for this model (3) Hausman test (175.62) is significant at $p<0.01$ with nine degrees of freedom, what suggest that the fixed effects estimations are more efficient and consistent than random effects ones.

INSERT TABLE 8 ABOUT HERE

Similarly with model (1) and (2), in the model (3) specification with year dummies variables we observe a significant ($p<0.01$) and negative effect for 2008 and 2009. When we entered all year dummies we also observed a reduction in the significance level of our explanatory variable. As we did in previous models, we have reduced the period of years of our panel data to explore the influence of these years on our model (3), excluding years 2008 and 2009 and replicating all estimations. Although we do not report here these results, we did not find any significant results for our explanatory variable.

In order to see graphically the behaviour of our model (3), we show the graphs for the adjusted prediction of *ROA* (as the measure of firm financial performance) by our explanatory variable *ACCRATE* (accident rate per worker), computed at means in the remaining control and dummies variables. Figures 5, 6 and 7 represent the estimated model (3) for the three different estimation procedures. As it can be seen, all figures illustrate that the estimated models predict an inverted U shape relationship between accident rate per worker and predicted ROA.

For pooled estimations (see Figure 5), the estimated model predicts a maximum *ROA* of 3.92 at an *ACCRATE* of 0.9633. For the case of random effects estimations (see Figure 6), the predicted maximum *ROA* (3.91) would be met at an *ACCRATE* of 0.9665. Finally, the estimated model using fixed effects (see Figure 7) the prediction for the maximum *ROA* is 4,03 which would be obtained with an *ACCRATE* of 0,9925.

In the following section we discuss our results and hypotheses testing.

Figure 5. Incidence of accidents rate (*ACCRATE* and *ACCRATE*^{2}, quadratic) on return of assets (*ROA*) in the same year. Pooled estimation.

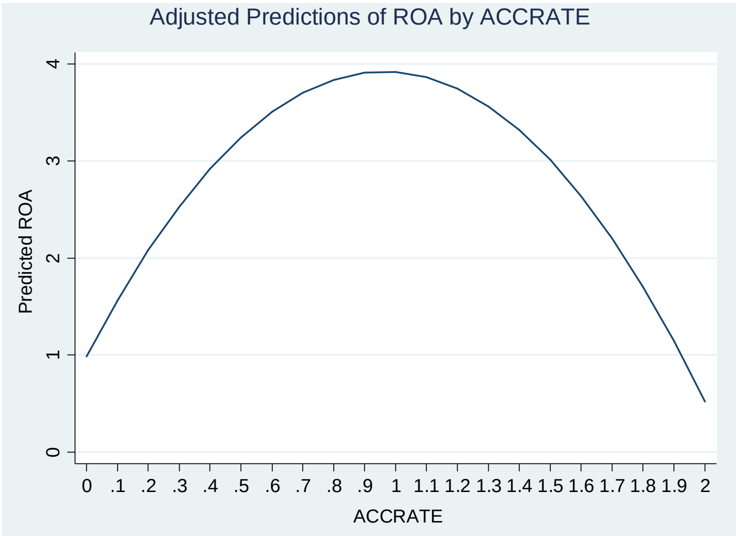


Figure 6. Incidence of accidents rate (*ACCRATE* and *ACCRATE*^{2}, quadratic) on return of assets (*ROA*) in the same year. Random effects estimation.

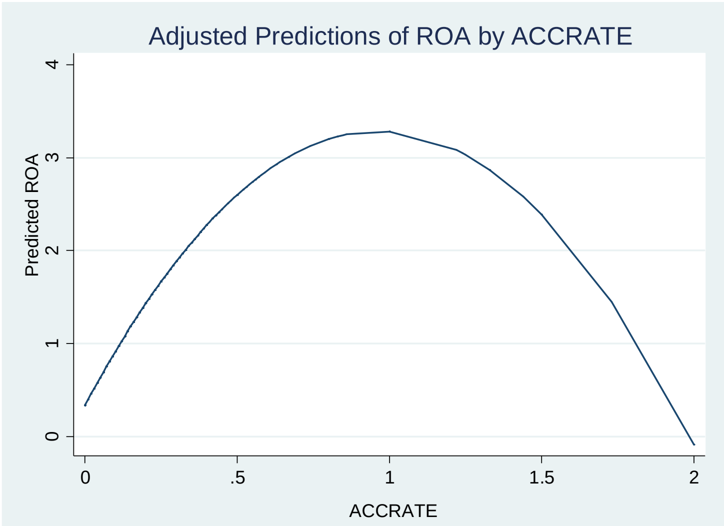
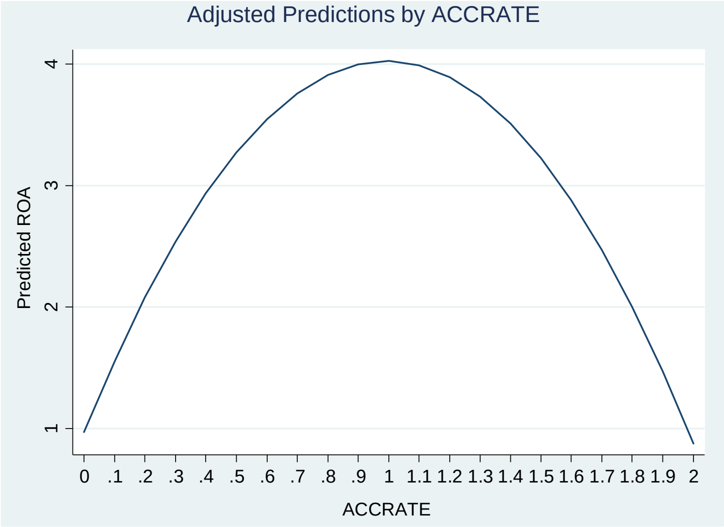


Figure 7. Incidence of accidents rate (*ACCRATE* and *ACCRATE*^{2}, quadratic) on return of assets (*ROA*) in the same year. Fixed effects estimation.



3.6. - Discussion and Conclusions

One of the most relevant differences of our study with traditional literature is that we try to explain the accident rate using a leading indicator with our variable *SRI* (Grabowski et al., 2007; J. Hinze et al., 2013; Rozenfeld et al., 2010; Sparer & Dennerlein, 2013). This is because, *SRI* contains relevant safety barriers on site, and assessing them we can provide better leading indicators (Kirsten Jørgensen, 2016). All the literature recognises that accidents cause disturbs at work, interfere in the normal development of tasks and finally entail direct and indirect costs (Fang et al., 2015; Ibarrondo-Dávila et al., 2015; López-Alonso et al., 2013). However, it does not seem to be a broad knowledge about the mechanisms that regulates the mutual relationship between the cost of accidents, on one side, and the costs of prevention and protection measures, on the other side. At least in theory, it has been proposed that a trade-off exists between the cost of accidents and the cost of prevention. But the problem in the practical application is that, although a high level of safety will always implies huge prevention costs, a low level of safety will not always be paired with high cost of accidents when they do not occur. In other words, since we always face the non-contingent nature of accident, it is important to adopt a longitudinal approach to show that sustained high level of risk on site increases the probability and the occurrence of accident.

All variables in our model (1) obtained the expected behaviour. *ORDGES* control variable is positive and significant (p<0.05) in the baseline and complete model, and SRI shows a significant (p<0.05) positive influence on accident rates (*ACCRATE*) (see Table 5, columns 7 and 8). More site risk generates more accidents according to pooled and random robust estimations with our complete model specification. The year dummies effects for 2008 and 2009 are significant. Since the world economic crisis that started on 2008 was especially important in Spain, and more acute in the construction sector, the significant estimations for the effects of 2008 and 2009 suggest that the recession might be affecting the relationships we are analysing. To verify this influence, we replicate the estimation of model (1) for the period 2004-2007. We confirm a significant positive relationship between *SRI* and *ACCRATE* (p<0.01) in pooled and random effects robust estimations (see Table 6, columns 7 and 8). All those robust results confirm our first hypothesis (H1). According to our results, we found empirical evidence of the existence of a lasting relationship between site risk level and the accident rates. Despite of the contingency dilemma between risk and accident and the fact that all likely accidents do not finally occur (Sundström-Frisk, 1985), we can conclude that when risk expositions are repeated along the time, the rate of accidents increases. We think that the present study can be taken as a first step in the direction of narrowing the knowledge gap regarding the connections between risk assessment processes and causality models of accidents (Khanzode et al., 2012). This result is an additional reason to decrease those risk expositions which has become so common in our site works that we do not properly think about them (Kirsten Jørgensen, 2016). However, as our results have showed the consequences of risk exposure will arrive sooner or later.

Regarding model (2) the behaviour of our control variables in the baseline models is as we expected. ROA_{t-1} is positive related with ROA_t (pooled and random estimations, $p<0.01$), and *CHASSETURN*, has a positive significant impact on *ROA* ($p<0.01$) for all alternative specifications and all estimation methods. But our study does not replicate the findings of Argilés-Bosch et al. (2014) as we do not find a significant negative linear relationship between accident rate on site and firm profitability. Despite our explanatory variable (*ACCRATE*) is positive and significant at $p<0.01$ for the fixed effects estimations (see Table 7, column 6), this significance disappears when year dummies are incorporated in the model specification (see Table 7 last column).

ROA is an economic variable that is affected by internal company factor but also by external economic conditions and other factors from social and political environments. Despite our models just focused on internal company factors, these other effects may affect the economic performance of the company. In our sample and the period of years analysed, this is especially important because of the strong economic crisis that started on 2008 and that might be influencing the relationships between the variables in our models. As we have explained and other similar recent research has done (Arguilés-Bosch, 2014), the effect of each specific period is captured by using year dummy variables, and the influence on *ROA* of all variables not explicitly considered in our models will be covered indirectly by the lagged *ROA* and the estimated error term. In addition, as in model (1), we performed all the estimation for a shorter period only considering the years 2004 to 2007, excluding the crisis period, and we did not found any significant effect of accident rate on ROA. According to this results we deduce that the influence of the crisis is probably affecting our model (2).

Our results are interesting in the sense that they do not replicate previous evidence. Argilés-Bosch et al. (2014) argued that accidents are unexpected and disturb works and they found evidence that the effect of accidents on firm profitability is produced one year ahead. We have also failed to reproduce these effects of accident in a previous year on current *ROA*. One possible explanation for the different results we have obtained can be in the particular period of data we have utilized and the specific sample of both studies. We have considered (2004-2009), a period during which the construction sector in Spain had an abnormal evolution, evolving from a rapid and intense growth of activity to a sudden severe stop and decline of the activity. Differently, Argilés-Bosch et al.'s (2014) studied a panel data from 1998 to 2003, where the sector faced a more stable environment. Although the type of construction firms considered in both studies were similar, local firms with headquarters in the region under analysis (Catalonia, and Balearic Islands in our case), both regions show a relevant difference in its accident rates. In fact, Balearic Islands accident rate has historically been one of the highest in Spain. One other aspect that differentiate both studies is that Argilés-Bosch et al. (2014) used a stratified quasi random sample formed by all firms with fatal and serious accidents completed by a random sample of firms reporting minor accidents. Our sample, on the contrary, has included a random sample of construction firms with and without accidents independently of their level of seriousness.

Despite these considerations, our empirical results provide some evidence that a positive relationship might exist between accidents rate and *ROA*. Obviously, we do not propose that this counter-intuitive finding can be linear. As we have discussed, we think that a quadratic specification might explain the increasing behaviour of *ROA* as accidents grow for a range of low levels of accident rates and, at the same time, a decreasing tendency of *ROA* when accident rate is at relatively high levels. This quadratic relationship between accidents and *ROA* may exist if there is a trade-off between the cost of safety measures (Gurcanli et al., 2015) and the accident cost (Feng et al., 2015), as we have discussed above. This quadratic specification can be also consistent with theoretical contributions from other scholars as for example, Behm et al. (2004), Chalos (1992) or (López-Alonso et al., 2013).

Having in mind the estimation results of our model 2 we have discussed previously, we wonder if would not be possible that a positive accident rate is indeed compatible with a strategy of benefits maximisation. In other words, might it be possible under certain circumstances to observe that an increment of the rate of accidents is compatible with an increase of *ROA*?

In order to analyse those questions, we have proposed to estimate our model (3) that hypothesises a quadratic relationship between accident rate and return on assets. As we can see in Table 8, our results are consistent with hypotheses H3a and H3b across the different estimations methods with the model specifications that only include control variables. However, these results do not maintain for the complete model specification that includes the year dummies. In those model specification we found evidence (at p<0,1 for pooled and fixed effects estimations and at p<0,05 for random effects estimations) for a significant negative quadratic effect (supporting H3b) but we only found a significant positive linear effect (supporting H3a) for the random effects estimates (p<0,1). In all models, the sign of the coefficients remains positive for the lineal regressor, *ACCRATE*, and negative for quadratic regressor, $ACCRATE^2$, which is in with of our hypothesis H3. Taking into account all these results, we can conclude that we partially confirm our hypothesis H3, as we have found a robust effect of the quadratic term of accident rate on *ROA*, even though when the significance level is not very strong.

When the number of accidents is relatively low, increments in accident rates will be associated with increments in *ROA*. This tendency change as we reach a tipping point where the relationship between accident rate and *ROA* turns to be negative. This slope sign change happens for a relatively high number of accidents, from which more accidents in a company will decrease its profitability. For the case of the random estimation with year dummies (column 5), the tipping point or maximum *ROA* is achieve at an accident rate of 0.967, and an increment of 1 point in the accident rate will have a positive linear effect of 6.10 and a negative effect of -3.16, the aggregate total effect of *ACCRATE* on *ROA* will depend on the specific level of *ACCRATE*. All the estimations in this model (3) showed in Table 8 present a significant goodness of fit at *p*<0.01 (random effects estimations of goodness of fit with complete dummy variables not reported).

Due to the lack of strong evidence supporting our hypothesis 3, we have explored in some additional depth the behaviour of the curvature of our adjusted predicted ROA functions. We have tried to confirm whether or not an inverted U shape relationship of accidents rate on *ROA* exists, looking at the significance of the decreasing part of this relationship (right part of the functions illustrated in Figures 5, 6 and 7). In doing so, for each estimation method, we have tested whether or not was significant the difference between predicted *ROA* at the tipping point (accident rate with maximum *ROA*) and the predicted *ROA* at the maximum accident rate in our sample. We have used STATA margins command to carry out those tests. The complete results from these tests are reported in Table 9. We have found significant differences for pooled estimations and random estimations at *p*<0.1, but we do not obtain a significant difference for fixed effects estimations. Globally, we interpret all these results as additional partial evidence supporting our hypothesis 3. It is interesting to note that the accident rate, *ACCRATE,* that yields the maximum predicted *ROA* is 0.974. This data can be taking as a very alarming number moreover when it is linked to the maximum predicted *ROA*, but we have to clarify that *ACCRATE* accounts for all types of accidents (fatal, serious and minor injuries). Additionally, this high data is not likely to be biased by our sample as it replicates fairly well the evolution of official incident rate for the whole construction sector (see Figure 3).

INSERT TABLE 9 ABOUT HERE

The confirmation of the decreasing part of our adjusted predicted *ROA* as a function of accident rate, makes compatible our results with those in Argilés-Bosch et al.'s (2014) study. Due to the range restriction in the sample these authors used, because they did not include any firm without accidents in their study, we deduce that they might be focused on the decreasing right side part of our quadratic model. However, as it follows from our results, it seems that at least under the environmental conditions of our empirical study (high growth in construction activity followed by a rapid sudden decline), it is possible to find a positive relationship between economic firm performance and the number of accidents they report. This increasing behaviour of *ROA* is only manifested for an inferior range of accident rate values, while for superior values in that variable the tendency turns to be decreasing.

Looking at our graphical results (see figures 5, 6 and 7), it seems that having a given number of accidents may be more efficient in economic terms than trying to eliminate them. In other words, there seems to be an optimal number of accidents, from a purely private economic point of view, which would differ from the optimal social objective of reducing or even eliminating accidents on constructions sites. Our results suggest, in the period and sample studied, hat the associated costs for accidents are not enough to affect negatively the profitability of the companies. This can be explained by the total effect of the two components of total cost of H&S, indirect costs of accidents and direct costs of prevention, as well as the existence of abnormal big benefits in the sector which might be able to bear most accident costs during long periods.

Our results would be the expected when there is a trade-off in these two costs components (prevention and accidents), as COS theory proposed (Chalos, 1992), in addition to the special economical evolution just discussed. It may well be that, for a specific range of accident rates, the increment in total H&S cost of having an additional accident will be lower than the increment in the total H&S cost of implementing the needed protections to try to avoid the accident. Certainly, we cannot compare directly COS theory where total cost of H&S are related with level of safety (see Figure 2) with the basis of our model (3) where we relate accidents that already happened and firm financial performance. This is because the problem of the contingency involved in the complex relationship between safety and accidents, as long as not all the risk exposition finally end in an accident. However, according to our empirical results analysing longitudinal data, we have found evidence in our hypothesis H1 for a positive relationship between risk (associated with poor levels of safety) and accidents. We take this as an argument to connect in some sense both models, COS theory and our model (3).

Another possible argument to explain the increasing part of our adjusted quadratic model (3), in addiction to COS theory, is that most construction firms were so extremely highly profitable during the years of the real-state bubble that they could absorb any kind of costs levels related with their operations, with includes H&S cost. This argument jointly with the prevailing absence of a culture of prevention in the sector and the low levels of professionalization would explain the evidence we have found of a positive relationship between accident rates and *ROA*. In fact, our results are partially in line with Ibarrondo-Dávila et al. (2015) who conclude that total H&S costs are substantial but they are not so onerous to erode financial firm performance.

In summary, our results suggest that, for a given level of investment in safety measures (probably low levels, investing not many resources in prevention activities), there may be a relatively long interval of positive accidents rate, that can have a positive final impact in the economic results of the firms. Obviously, the positive effect of accident rate on *ROA* should disappear for relatively high accident rates, as the effects of a large number of accidents at work will necessarily harm the economic results of the firm (for example, because of high direct costs of accidents and/or sanctions) offsetting any potential gains coming from doing less in term of preventive actions.

One interesting practical and political implication is that if we allow that construction firms make decisions from a pure economic perspective, they will probably never invest enough in safety preventive measures. According to our results, only after arriving to a too high accident rate of 0.974, companies will start to suffer a negative impact on their financial results. This suggests that may result economically profitable maintaining high accident rates, especially in context of increasing production and consequently profits, which implies a clear conflict of interest from a social perspective. We claim that social and private interests should be aligned in order to reduce the high accident rates in the construction sector. This can be done mainly in two ways: investing higher amount of resources (financial, technical, human, etc.) and implementing several policy interventions based in two axis, safety promotion and safety control. For the first course of action, we think that Public Administration should promote more effective awareness campaigns of H&S, offer aids to make more efficient the safety management in firms or promote more appropriate and extensive training to workers and managers, among others. Related to the second course of action, we believe that might be helpful to implement harder supervision mechanisms and imposing stronger sanctions to those companies who does not strictly follow safety regulations. Facilitating and coercive approaches will be aimed to the same final goal: reduce the expositions to risks and make unprofitable for companies any deviation from the social optimal level of safety.

Facing the two intervention ways, it would be preferable to turn the focus on more proactive approach by looking at leading indicators on site such as safety barriers and organizational structure on site (Bellamy et al., 2008; Jørgensen, 2016; and paper 2 chapter 2). Therefore, we think that those policies that direct the focus towards the verification of an adequate level of resources and structure on sites and also towards the periodical checking of the sites live conditions, are preferable than policies aimed to penalise high accident rates. The later are reactive actions which do not avoid the accidents, they just penalise its occurrence in economical terms. We think that this kind of measures must be applied only for extremely cases because they are clearly indicating that all preventive system is failing.

3.7. - Limitations and future challenges

Despite our relevant contributions, our research has some limitations. First, the data we have used to build our risk index, SRI, and the control variable *ORGDES* in the model (1) were collected on construction sites, i.e. they are variables at site level unit of analysis, while the dependent variable *ACCRATE* is a measure at level of the whole company. Since we did not have both variables measures for all sites of each company, we use mean of the observations associated to a given company. Since we did not confirm whether or not those sites were representative of the whole company sites, the validity of our results should be tested. In this sense, future studies must complete measures of *SRI* considering the most representative sites of each company.

Another limitation is to assess the financial firm performance just in terms of *ROA*, without take in account other variables related for example with direct and indirect cost of the accidents, for the companies, workers or society in general (Feng et al. ,2015; Ibarrondo-Dávila et al., 2015).

An additional limitation of this study is that the estimated R-squared values of our adjusted models are quite low. Although *ROA* is a variable that is in fact depending of a lot of factors, we think it is necessary to undertake more empirical research, with other kind of samples, in order to check if we can explain a higher percentage of the variance of our dependent variable.

As we have commented in previous section, in our sample we have firms with accidents as well as without accidents. The idea of non-contingency between risk and accidents, make plausible the existence of different models for relating risk/safety with accidents. In our sample we have nearly 45% of zero accident observations. We explored the possibility that the process behind zero accident level cases was different to the process behind a positive level of accident cases. We do not find significant evidence for these different processes and therefore, we did not introduce any corrections for zero inflated in our model (1). Even though, we think this issue should be analysed in future empirical studies, addressing the relevant issue of the non-contingency between risk and accidents.

Considering that the robustness of our results in model (3) is limited, would be convenient to estimate these models with new periods of years with a smoother evolution of the activity. The sample and period we have considered in this study can limit the possibility of generalizing our results because of their specific characteristics.

A future challenge is to propose and test a model of the relationships between SRI and *ROA* mediated by *ACCRATE*, to verify if only when accidents occurs, and in a sufficient number, SRI affect firm financial performance, while risk conditions on sites by themselves do not affect directly to firm performance.

Another research line should be directed to study if there exist causal relationships between organizational resources on sites, accidents rates and firm financial performance. One direction might be try to analyse in which proportion the evolution of firm performance is influenced by the level of organisational effectiveness or by the costs of no safety, as well as the influence between both last elements. Are those sites with better organisational elements and structures safer? And consequently, are they more efficient and profitable?

At last, a future research line can be develop to connect COS theory (Chalos, 1992) with an approach of expected total cost of H&S. As Figure 2 illustrates this author relate safety levels with effective cost of occurred accidents. In this framework, it is ignored that more level of safety tends to make less likely the occurrence of the accidents and from the point of view of a company what it is relevant in its decision making process would be the total expected cost of H&S for a given level of safety. We think that more theoretical and empirical works are needed in this direction.

3.8. - Acknowledgements

Balearic Islands Labour Authority for provide us data of accidents that has made possible our research.

4. - Discussion

The main objectives of this research has been to build a new tool to assess the construction site risk, and then to use this tool to capture safety risk conditions on site and organizational resources levels. Finally, the aim is to use all these data to test the relationships proposed for our hypothesis, that are mainly involved with the levels of risk with organizational factors and accident rates, and, to finish, accident rates with firm economic performance.

We have designed a new tool allowing the characterization of the site in terms of its risks and organisational structure. We have achieved the whole site evaluation that tries to capture synergies; this is the most important difference and main contribution of our tool comparison with other current models. Another contribution of CONSRAT, that makes it different from other current methods, is it captures risk as well as organizational variables. It lets us perform posterior site analysis, proposing the concrete interventions directly on site live conditions and site structure or necessary resources. The tool gives us a prioritized risk estimation with alarm variables that are essential for interventions.

Using CONSRAT, we have built a SEM model to test the relationships between organizational complexity and resources as potential predictors for risk level on construction sites. In this model, risk level on site is related to four latent variables built from CONSRAT's organizational variables. We have obtained a positive direct effect of site complexity on SRI and a negative direct effect of safety management resources on SRI. However, the strongest effect on SRI is caused by the latent variables of organizational structure resources and organization design complexity. Our results are in part consistent with the evidence found in previous researches. Mainly relating the relationship between site complexity and SRI (Fang et al., 2004; Forman, 2013; Hatipkarasulu, 2010; Hon et al., 2010; Manu et al., 2010), and the relation of organizational structure resources, in the relation between promoter and risk (Baxendale & Jones, 2000; Behm, 2005; Hinze et al., 2013; Ros et al., 2013; Xinyu et al., 2006). On the topic of organizational design and complexity, previous research has found that more subcontracting leads to worst safety levels (J. Hinze, Thurman, et al., 2013; López-Alonso et al., 2013; Manu et al., 2013; Swuste et al., 2012; Yung, 2009), and the total number of workers are related in previous researches with a negative effect on H&S on sites, (Fang et al., 2004; López-Alonso et al., 2013). On the topic of safety management resources, our results are consistent with previous research that relates preventive functions of the structure at the level of H&S (Baxendale & Jones, 2000; Borys, 2012; D. P. Fang, Huang, et al., 2004; Jarvis & Tint, 2009; Manu et al., 2013).

Finally, in the present study we have analysed the connections between risk conditions on site and accidents rates, and the relationship between accident rates and firm financial performance. We have obtained significant evidence of the positive influence of risk on site (*SRI*) on accident rates (*ACCRATE*). More level of risk generates more accidents according to pooled and random robust estimations with our complete model specification that includes dummies of years. According to our results, we have found empirical evidence of the existence of a lasting relationship between accidents and level of risk. To complete this latter study, we can partiality confirm the quadratic influence between accidents rates and economic performance. The results are not significant in all our estimations when we included the year dummies. We have tried to confirm whether or not an inverted U shape relationship of accidents rate on *ROA* exists, looking at the significance of the decreasing part of this relationship. We have found significant differences for pooled estimations and random estimations. We interpret all these results as additional partial evidence supporting our last hypothesis. The confirmation of the decreasing part of our adjusted predicted ROA as a function of accident rate makes compatible our results with those in Argilés-Bosch et al.'s (2014) study. However, as it follows from our results, it seems that at least under the environmental conditions of our empirical study, it is possible to find a positive relationship between economic firm performance and the number of accidents they report.

5. - Conclusions

We can highlight the main contributions of present research summarising as follows:

- We have proposed a new way to assess the risk associated to construction sites. With this method (CONSRAT), we can get an overall evaluation of the risk associated to the whole site, which captures synergies by assessing together risk levels of specific scenarios as well as risk level associated to organizational aspects of the site structure. After using CONSRAT we have obtained integrated site information to be used as an active leading indicator (Hinze et al., 2013; Grabowski et al., 2007) in order to define and implement interventions in both material conditions and site organization. Since CONSRAT is also a tool that captures information at task level, we have contributed to fill the literature gap identified by the research stream that claims there is a lack of exposition measures (Swuste et al., 2012; Zhou et al., 2015).

- About the relationship between organizational factors and risk, we have found evidence of a direct and significant impact of organizational elements on the level of risk on site (SRI). The relevance of these findings is that the organizational variables we have considered can be used as predictor of risk on site and therefore they have important implications on H&S interventions. Our results showed that the risk on site is mainly affected by organizational structure and organizational design complexity. These variables are related with promoter role and constructor's management structure, and their implication through assuming preventive functions affecting safety levels on site. In this field is also important the type of contracting, the number of companies and level of subcontracting. Finally, within the set of resources variables, which include general and safety management resources, the preventive functions from persons in charge are one of the most essential factor to affect safety levels. Our study points out that we can achieve better safety levels on site having more professionalised companies, with adequate and stable structures, and assuring the active presence and preventive control on works by the assignment of the appropriate human resources. It is important also to limit the number of contractors or the total number of companies on site.

- Finally, we have analysed the relationship between level of risk on accident rates and also the relationship between accident rates on financial performance. We find evidence about the significant relationship of risk on accident rates, and we have partially confirmed the quadratic influence between accidents rates and economic performance. The relevance of those findings is twofold. On the one hand, the empirical evidence of the positive significant effect of risk level on accidents rates, contributing with new findings to the inherent dilemma of the contingency between these issues. On the other hand, the new findings from our sample points out to the existence of a quadratic relationship between accident rates and firm economic performance, showing that the cost from the accidents are not enough to affect negatively the profitability of firms. We conclude that is important to consider the combined effect of both H&S costs, accident costs and prevention/protection costs, when we want to analyse final firm performance. Since our evidence shows that under certain conditions it is possible to observe together increasing accidents rates and growing benefits for companies, it is necessary more safety promotion and control by Public Administration in order to aligned private and social interests.

References

Abudayyeh, O., Fredericks, T. K., Butt, S. E., & Shaar, A. (2006). An investigation of management's commitment to construction safety. *International Journal of Project Management*, *24*(2), 167–174. http://doi.org/10.1016/j.ijproman.2005.07.005

Adam, J. M., Pallarés, F. J., & Calderón, P. A. (2009). Falls from height during the floor slab formwork of buildings: Current situation in Spain. *Journal of Safety Research*, *40*(4), 293–299. http://doi.org/10.1016/j.jsr.2009.07.003

Ale, B. J. M. (2006). The Occupational Risk Model – Final Report of the Workgroup on ORM. s.l.: Technical University Delft.

Ale, B. J. M., Baksteen, H., Bellamy, L. J., Bloemhof, A., Goossens, L., Hale, A., Whiston, J. Y. (2008). Quantifying occupational risk: The development of an occupational risk model. *Safety Science*, *46*(2), 176–185. http://doi.org/10.1016/j.ssci.2007.02.001

Aneziris, O. N., Papazoglou, I. A., Baksteen, H., Mud, M., Ale, B. J., Bellamy, L. J, Oh, J. (2008). Quantified risk assessment for fall from height. *Safety Science*, *46*(2), 198–220. http://doi.org/10.1016/j.ssci.2007.06.034

Aneziris, O. N., Papazoglou, I. A., & Kallianiotis, D. (2010). Occupational risk of tunneling construction. *Safety Science*, *48*(8), 964–972. http://doi.org/10.1016/j.ssci.2009.11.003

Argilés-Bosch, J. M., Martí, J., Monllau, T., Garcia-Blandón, J., & Urgell, T. (2014). Empirical analysis of the incidence of accidents in the workplace on firms' financial performance. *Safety Science*, *70*, 123–132. http://doi.org/10.1016/j.ssci.2014.05.012

Baksteen, H., Mud, M., & Bellamy, L. J. (2007). Accident Analysis using Storybuilder. http://www.employment.belgium.be/home.aspx. Retrieved from http://www.employment.belgium.be/home.aspx

Bandyopadhyay, S. P., Chen, C., Huang, A. G., & Jha, R. (2010). Accounting Conservatism and the Temporal Trends in Current Earnings' Ability to Predict Future Cash Flows versus Future Earnings: Evidence on the Trade-off between Relevance and Reliability*. *Contemporary Accounting Research*, *27*(2), 413–460. http://doi.org/10.1111/j.1911-3846.2010.01013.x

Baxendale, T., & Jones, O. (2000). Construction design and management safety regulations in practice--progress on implementation. *International Journal of Project Management*, *18*(1), 33–40. http://doi.org/10.1016/S0263-7863(98)00066-0

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

Behm, M., Veltri, A., & Kleinorge, I. K. (2004). The cost of safety. *Professional Safety*, *49(4)*, 22–29.

Bellamy, L. J. (2009). Process safety indicators: Response to Andrew Hopkins. *Safety Science*, *47*(4), 472–473. http://doi.org/10.1016/j.ssci.2008.07.039

Bellamy, L. J. (2010). Which management system failure are responsible for occupational accidents? Saf. Sci. Monit., 14 (1).

Bellamy, L. J. (2015). Exploring the relationship between major hazard, fatal and non-fatal accidents through outcomes and causes. *Safety Science*, *71*, *Part B*, 93–103. http://doi.org/10.1016/j.ssci.2014.02.009

Bellamy, L. J., Ale, B. J. M., Geyer, T. A. W., Goossens, L. H. J., Hale, A. R., Oh, J., … Whiston, J. Y. (2007). Storybuilder—A tool for the analysis of accident reports. *Reliability Engineering & System Safety*, *92*(6), 735–744. http://doi.org/10.1016/j.ress.2006.02.010

Bellamy, L. J., Geyer, T. A. W., & Wilkinson, J. (2008). Development of a functional model which integrates human factors, safety management systems and wider organisational issues. *Safety Science*, *46*(3), 461–492. http://doi.org/10.1016/j.ssci.2006.08.019

Bellamy, L. J., Mud, M., Manuel, H. J., & Oh, J. I. H. (2013). Analysis of underlying causes of investigated loss of containment incidents in Dutch Seveso plants using the

Storybuilder method. *Journal of Loss Prevention in the Process Industries*, *26*(6), 1039–1059. http://doi.org/10.1016/j.jlp.2013.03.009
Borys, D. (2012). The role of safe work method statements in the Australian construction industry. *Safety Science*, *50*(2), 210–220. http://doi.org/10.1016/j.ssci.2011.08.010
Brody, B., Létourneau, Y., & Poirier, A. (1990). An indirect cost theory of work accident prevention. *Journal of Occupational Accidents*, *13*(4), 255–270. http://doi.org/10.1016/0376-6349(90)90033-R
Cambraia, F. B., Saurin, T. A., & Formoso, C. T. (2010). Identification, analysis and dissemination of information on near misses: A case study in the construction industry. *Safety Science*, *48*(1), 91–99. http://doi.org/10.1016/j.ssci.2009.06.006
Camino López, M. A., Ritzel, D. O., Fontaneda González, I., & González Alcántara, O. J. (2011). Occupational accidents with ladders in Spain: Risk factors. *Journal of Safety Research*, *42*(5), 391–398. http://doi.org/10.1016/j.jsr.2011.08.003
Camino López, M. A., Ritzel, D. O., Fontaneda, I., & González Alcantara, O. J. (2008). Construction industry accidents in Spain. *Journal of Safety Research*, *39*(5), 497–507. http://doi.org/10.1016/j.jsr.2008.07.006
Chalos, P. (1992). Managing cost in today's manufacturing environment. *Prentice Hall, Englewood Cliffs, NJ.*
Cheng, C.-W., Leu, S.-S., Cheng, Y.-M., Wu, T.-C., & Lin, C.-C. (2012). Applying data mining techniques to explore factors contributing to occupational injuries in Taiwan's construction industry. *Accident Analysis & Prevention*, *48*, 214–222. http://doi.org/10.1016/j.aap.2011.04.014
Cheng, C.-W., Lin, C.-C., & Leu, S.-S. (2010). Use of association rules to explore cause–effect relationships in occupational accidents in the Taiwan construction industry. *Safety Science*, *48*(4), 436–444. http://doi.org/10.1016/j.ssci.2009.12.005
Cheng, Q. (2005). The Role of Analysts' Forecasts in Accounting-Based Valuation: A Critical Evaluation. *Review of Accounting Studies*, *10*(1), 5–31. http://doi.org/10.1007/s11142-004-6338-4
Conte, J. C., Rubio, E., García, A. I., & Cano, F. (2011). Occupational accidents model based on risk–injury affinity groups. *Safety Science*, *49*(2), 306–314. http://doi.org/10.1016/j.ssci.2010.09.005
Donaghy, R. (2009). One-death-is-too-many. *Secretary of State Report UK.*
Edwards, W., & Newman, J. R. (1982). Multiattribute evaluation. *California, CA: Sage Publications*, 52–58.
EUROSTAT. (2004). Eurostat, 2004. Statistical Analysis of Socio-economic Costs of Accidents at Work in the European Union. s.l.: European Commission. Retrieved from http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hsw_aw_inaws&lang=en
Fairfield, P. M., & Yohn, T. L. (2001). Using Asset Turnover and Profit Margin to Forecast Changes in Profitability. *Review of Accounting Studies, 6*(4), 371–385. http://doi.org/10.1023/A:1012430513430
Fang, D., Jiang, Z., Zhang, M., & Wang, H. (2015). An experimental method to study the effect of fatigue on construction workers' safety performance. *Safety Science*, *73*, 80–91. http://doi.org/10.1016/j.ssci.2014.11.019
Fang, D. P., Huang, X. Y., & Hinze, J. (2004). Benchmarking Studies on Construction Safety Management in China. *Journal of Construction Engineering & Management*, *130*(3), 424–432. http://doi.org/10.1061/(ASCE)0733-9364(2004)130:3(424)
Fang, D. P., Xie, F., Huang, X. Y., & Li, H. (2004). Factor analysis-based studies on construction workplace safety management in China. *International Journal of Project Management*, *22*(1), 43–49. http://doi.org/10.1016/S0263-7863(02)00115-1

Feng, Y., Zhang, S., & Wu, P. (2015). Factors influencing workplace accident costs of building projects. *Safety Science*, *72*, 97–104. http://doi.org/10.1016/j.ssci.2014.08.008

Fernández-Muñiz, B., Montes-Peón, J. M., & Vázquez-Ordás, C. J. (2009). Relation between occupational safety management and firm performance. *Safety Science*, *47*(7), 980–991. http://doi.org/10.1016/j.ssci.2008.10.022

Forman, M. (2013). Inertia and change: lean construction and health and safety work on construction sites. *Construction Management & Economics*, *31*(6), 647–660. http://doi.org/10.1080/01446193.2013.765953

Gavious, A., Mizrahi, S., Shani, Y., & Minchuk, Y. (2009). The costs of industrial accidents for the organization: Developing methods and tools for evaluation and cost-benefit analysis of investment in safety. *Journal of Loss Prevention in the Process Industries*, *22*(4), 434–438. http://doi.org/10.1016/j.jlp.2009.02.008

Ghasemi, F., Mohammadfam, I., Soltanian, A., Mahmoudi, S., & Zarei, E. (n.d.). Surprising Incentive: An Instrument for Promoting Safety Performance of Construction Employees. *Safety and Health at Work*. http://doi.org/10.1016/j.shaw.2015.02.006

Grabowski, M., Ayyalasomayajula, P., Merrick, J., & McCafferty, D. (2007). Accident precursors and safety nets: Leading indicators of tanker operations safety. *Maritime Policy and Management*, *34*(5), 405–425. http://doi.org/10.1080/03088830701585084

Gurcanli, G. E., Bilir, S., & Sevim, M. (2015). Activity based risk assessment and safety cost estimation for residential building construction projects. *Safety Science*, *80*, 1–12. http://doi.org/10.1016/j.ssci.2015.07.002

Hale, A. R., Ale, B. J. M., Goossens, L. H. J., Heijer, T., Bellamy, L. J., Mud, M. L., Oh, J. I. H. (2007). Modeling accidents for prioritizing prevention. *Reliability Engineering & System Safety*, *92*(12), 1701–1715. http://doi.org/10.1016/j.ress.2006.09.025

Hale, A. R., Goossens, L. H. J., Ale, B. J. M., Bellamy, L. A., Post, J., Oh, J. I. H., & Papazoglou, I. A. (2004). Managing safety barriers and controls at the workplace. *Probabilistic Safety Assessment & Management*, 608–613.

Hallowell, M. (2011). Risk-Based Framework for Safety Investment in Construction Organizations. *Journal of Construction Engineering and Management*, *137*(8), 592–599. http://doi.org/10.1061/(ASCE)CO.1943-7862.0000339

Hallowell, M., & Gambatese, J. (2009). Construction Safety Risk Mitigation. *Journal of Construction Engineering and Management*, *135*(12), 1316–1323. http://doi.org/10.1061/(ASCE)CO.1943-7862.0000107

Hallowell, M., & Gambatese, J. (2010). Population and Initial Validation of a Formal Model for Construction Safety Risk Management. *Journal of Construction Engineering and Management*, *136*(9), 981–990. http://doi.org/10.1061/(ASCE)CO.1943-7862.0000204

Harshbarger, D. (2001). Managing safety from the executive suite. *Occupational Health & Safety (Waco, Tex.)*, *70*(10), 28–30, 32, 34–36.

Hatipkarasulu, Y. (2010). Project level analysis of special trade contractor fatalities using accident investigation reports. *Journal of Safety Research*, *41*(5), 451–457. http://doi.org/10.1016/j.jsr.2010.08.005

Heinrich, H. (1927). *The incidental cost of accidents*.

Heinrich, H. (1941). Industrial Accident Prevention a Scientific Approach. *(second ed.)McGraw-Hill Book Company, London (1941)*.

Hinze, J., Hallowell, M., & Baud, K. (2013). Construction-Safety Best Practices and Relationships to Safety Performance. *Journal of Construction Engineering and Management*, *139*(10), 04013006. http://doi.org/10.1061/(ASCE)CO.1943-7862.0000751

Hinze, J., Thurman, S., & Wehle, A. (2013). Leading indicators of construction safety performance. *Safety Science*, *51*(1), 23–28. http://doi.org/10.1016/j.ssci.2012.05.016
Hinze, J. W., & Teizer, J. (2011). Visibility-related fatalities related to construction equipment. *Safety Science*, *49*(5), 709–718. http://doi.org/10.1016/j.ssci.2011.01.007
Hoewijk, V. R. (1988). De betekenis van de organisatiecultuur: een literatuuroverzicht (The meaning of organisational culture: an overview of the literature). *M & O, Tijdschrift Voor Organisatiekunde En Sociaal Beleid 1, 4– 46.*
Hollnagel, E. (2008). Risk + barriers = safety? *Safety Science*, *46*(2), 221–229. http://doi.org/10.1016/j.ssci.2007.06.028
Holte, K. A., Kjestveit, K., & Lipscomb, H. J. (2015). Company size and differences in injury prevalence among apprentices in building and construction in Norway. *Safety Science*, *71*, *Part C*, 205–212. http://doi.org/10.1016/j.ssci.2014.01.007
Hon, C. K. H., Chan, A. P. C., & Wong, F. K. W. (2010). An analysis for the causes of accidents of repair, maintenance, alteration and addition works in Hong Kong. *Safety Science*, *48*(7), 894–901. http://doi.org/10.1016/j.ssci.2010.03.013
HSE. (2009). Health and Safety Executive. Underlying Causes of Construction Fatal Accidents – A Comprehensive Review of Recent Work to Consolidate and Summarize Existing Knowledge, Phase 1 Report. Construction Division. Her Majesty’s Stationary office, Norwich.
HSE. (2015). Costs to Britain of workplace fatalities and self-reported injuries and ill health, 2013/14. Retrieved from http://www.hse.gov.uk/statistics/pdf/cost-to-britain.pdf
Hsiao, C. (2014). *Analysis of Panel Data* (3rd ed.). Cambridge: Cambridge University Press. Retrieved from http://ebooks.cambridge.org/ref/id/CBO9781139839327
Hu, L., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal*, *6*(1), 1–55. http://doi.org/10.1080/10705519909540118
Ibarrondo-Dávila, M. P., López-Alonso, M., & Rubio-Gámez, M. C. (2015). Managerial accounting for safety management. The case of a Spanish construction company. *Safety Science*, *79*, 116–125. http://doi.org/10.1016/j.ssci.2015.05.014
Jarvis, M., & Tint, P. (2009). The Formation of a Good Safety Culture at Enterprise. *Journal of Business Economics and Management*, *10*(2), 169–180.
Jöreskog, K. G., & Sörbom, D. (2006). LISREL 8.80 for Windows [Computer Software]. Lincolnwood, IL: Scientific Software International, Inc.
Jørgensen, K. (2011). A tool for safety officers investigating “simple” accidents. *Safety Science*, *49*(1), 32–38. http://doi.org/10.1016/j.ssci.2009.12.023
Jørgensen, K. (2016). Prevention of “simple accidents at work” with major consequences. *Safety Science*, *81*, 46–58. http://doi.org/10.1016/j.ssci.2015.01.017
Jørgensen, K., Duijm, N. J., & Troen, H. (2010). Accident prevention in SME using ORM. *Safety Science*, *48*(8), 1036–1043. http://doi.org/10.1016/j.ssci.2010.02.008
Khanzode, V. V., Maiti, J., & Ray, P. K. (2012). Occupational injury and accident research: A comprehensive review. *Safety Science*, *50*(5), 1355–1367. http://doi.org/10.1016/j.ssci.2011.12.015
Knegtering, B., & Pasman, H. J. (2009). Safety of the process industries in the 21st century: A changing need of process safety management for a changing industry. *Journal of Loss Prevention in the Process Industries*, *22*(2), 162–168. http://doi.org/10.1016/j.jlp.2008.11.005
Körvers, P. M. W., & Sonnemans, P. J. M. (2008). Accidents: A discrepancy between indicators and facts! *Safety Science*, *46*(7), 1067–1077. http://doi.org/10.1016/j.ssci.2007.06.004

Labelle, J. E. (2000). What do accidents truly cost? - ProQuest. *Professional Safety*, *45*(4), 38–42.
Laitinen, H., Marjamäki, M., & Päivärinta, K. (1999). The validity of the TR safety observation method on building construction. *Accident Analysis & Prevention*, *31*(5), 463–472. http://doi.org/10.1016/S0001-4575(98)00084-0
Laitinen, H., & Päivärinta, K. (2010). A new-generation safety contest in the construction industry - A long-term evaluation of a real-life intervention. *Safety Science*, *48*(5), 680–686. http://doi.org/10.1016/j.ssci.2010.01.018
Laitinen, H., & Ruohomäki, I. (1996). The effects of feedback and goal setting on safety performance at two construction sites. *Safety Science*, *24*(1), 61–73. http://doi.org/10.1016/S0925-7535(96)00070-7
Larsson, T. J., & Field, B. (2002). The distribution of occupational injury risks in the Victorian construction industry. *Safety Science*, *40*(5), 439–456. http://doi.org/10.1016/S0925-7535(01)00015-7
Liao, C.-W., & Perng, Y.-H. (2008). Data mining for occupational injuries in the Taiwan construction industry. *Safety Science*, *46*(7), 1091–1102. http://doi.org/10.1016/j.ssci.2007.04.007
Liu, J., Zou, P., & Gong, W. (2013). Managing Project Risk at the Enterprise Level: Exploratory Case Studies in China. *Journal of Construction Engineering and Management*, *139*(9), 1268–1274. http://doi.org/10.1061/(ASCE)CO.1943-7862.0000717
Loehlin, J. C. (2004). *Latent Variable Models: An Introduction to Factor, Path, and Structural Equation Analysis*. Psychology Press.
López-Alonso, M., Ibarrondo-Dávila, M. P., Rubio-Gámez, M. C., & Munoz, T. G. (2013). The impact of health and safety investment on construction company costs. *Safety Science*, *60*, 151–159. http://doi.org/10.1016/j.ssci.2013.06.013
López Arquillos, A., Rubio Romero, J. C., & Gibb, A. (2012). Analysis of construction accidents in Spain, 2003-2008. *Journal of Safety Research*, *43*(5–6), 381–388. http://doi.org/10.1016/j.jsr.2012.07.005
Mahmoudi, S., Ghasemi, F., Mohammadfam, I., & Soleimani, E. (2014). Framework for Continuous Assessment and Improvement of Occupational Health and Safety Issues in Construction Companies. *Safety and Health at Work*, *5*(3), 125–130. http://doi.org/10.1016/j.shaw.2014.05.005
Manuele, F., & Main, B. W. (2002). On acceptable risk. *Occupational Hazards*, *1*, 57–60.
Manu, P., Ankrah, N., Proverbs, D., & Suresh, S. (2010). An approach for determining the extent of contribution of construction project features to accident causation. *Safety Science*, *48*(6), 687–692. http://doi.org/10.1016/j.ssci.2010.03.001
Manu, P., Ankrah, N., Proverbs, D., & Suresh, S. (2013). Mitigating the health and safety influence of subcontracting in construction: The approach of main contractors. *International Journal of Project Management*, *31*(7), 1017–1026. http://doi.org/10.1016/j.ijproman.2012.11.011
Ma, Y., Zhao, Q., & Xi, M. (2016). Decision-makings in safety investment: An opportunity cost perspective. *Safety Science*, *83*, 31–39. http://doi.org/10.1016/j.ssci.2015.11.008
McVittie, D., Banikin, H., & Brocklebank, W. (1997). The effects of firm size on injury frequency in construction. *Safety Science*, *27*(1), 19–23. http://doi.org/10.1016/S0925-7535(97)00048-9
Memarian, B., & Mitropoulos, P. (2013). Accidents in masonry construction: The contribution of production activities to accidents, and the effect on different worker groups. *Safety Science*, *59*, 179–186. http://doi.org/10.1016/j.ssci.2013.05.013

Mohamed, S. (1999). Empirical investigation of construction safety management activities and performance in Australia. *Safety Science*, *33*(3), 129–142. http://doi.org/10.1016/S0925-7535(99)00028-4
Nishikitani, M., & Yano, E. (2008). Differences in the lethality of occupational accidents in OECD countries. *Safety Science*, *46*(7), 1078–1090. http://doi.org/10.1016/j.ssci.2007.06.017
Niskanen, T., Louhelainen, K., & Hirvonen, M. L. (2016). A systems thinking approach of occupational safety and health applied in the micro-, meso- and macro-levels: A Finnish survey. *Safety Science*, *82*, 212–227. http://doi.org/10.1016/j.ssci.2015.09.012
Pérez-Alonso, J., Carreño-Ortega, Á., Callejón-Ferre, Á. J., & Vázquez-Cabrera, F. J. (2011). Preventive activity in the greenhouse-construction industry of south-eastern Spain. *Safety Science*, *49*(2), 345–354. http://doi.org/10.1016/j.ssci.2010.09.013
Pinto, A. (2014). QRAM a Qualitative Occupational Safety Risk Assessment Model for the construction industry that incorporate uncertainties by the use of fuzzy sets. *Safety Science*, *63*, 57–76. http://doi.org/10.1016/j.ssci.2013.10.019
Pinto, A., Nunes, I. L., & Ribeiro, R. A. (2011). Occupational risk assessment in construction industry - Overview and reflection. *Safety Science*, *49*(5), 616–624. http://doi.org/10.1016/j.ssci.2011.01.003
Rechenthin, D. (2004). Project safety as a sustainable competitive advantage. *Journal of Safety Research*, *35*(3), 297–308. http://doi.org/10.1016/j.jsr.2004.03.012
Ros, A., Ortiz-Marcos, I., Uruburu, A., & Palomo, J. G. (2013). A proposal for improving safety in construction projects by strengthening coordinators' competencies in health and safety issues. *Safety Science*, *54*, 92–103. http://doi.org/10.1016/j.ssci.2012.12.004
Rozenfeld, O., Sacks, R., Rosenfeld, Y., & Baum, H. (2010). Construction Job Safety Analysis. *Safety Science*, *48*(4), 491–498. http://doi.org/10.1016/j.ssci.2009.12.017
Rubio-Romero, J. C., Carmen Rubio Gámez, M., & Carrillo-Castrillo, J. A. (2013). Analysis of the safety conditions of scaffolding on construction sites. *Safety Science*, *55*, 160–164. http://doi.org/10.1016/j.ssci.2013.01.006
Schreiber, J. B., Stage, F. K., King, J., Nora, A., & Barlow, E. A. (2006). Reporting Structural Equation Modeling and Confirmatory Factor Analysis Results: A Review. *The Journal of Educational Research*, *99*(6), 323–337. http://doi.org/10.3200/JOER.99.6.323-338
Sesé. (2003). *Un modelo de estructura de covariancias sobre Seguridad Laboral [A occupational safety structural equation model]*. Valencia: Edicions UVEG.
Sgourou, E., Katsakiori, P., Goutsos, S., & Manatakis, E. (2010). Assessment of selected safety performance evaluation methods in regards to their conceptual, methodological and practical characteristics. *Safety Science*, *48*(8), 1019–1025. http://doi.org/10.1016/j.ssci.2009.11.001
Spangenberg, S., Mikkelsen, K. ., Kines, P., Dyreborg, J., & Baarts, C. (2002). The construction of the Øresund Link between Denmark and Sweden: the effect of a multi-faceted safety campaign. *Safety Science*, *40*(5), 457–465. http://doi.org/10.1016/S0925-7535(01)00013-3
Sparer, E. H., & Dennerlein, J. T. (2013). Determining safety inspection thresholds for employee incentives programs on construction sites. *Safety Science*, *51*(1), 77–84. http://doi.org/10.1016/j.ssci.2012.06.009
Sundström-Frisk, F. (1985). Kurs i Säkerhetsanalys. *Arbetarskyddsstyrelsen, Stockholm*.
Swuste, P., Frijters, A., & Guldenmund, F. (2012). Is it possible to influence safety in the building sector?: A literature review extending from 1980 until the present. *Safety Science*. http://doi.org/10.1016/j.ssci.2011.12.036

Swuste, P., Gulijk, C. van, & Zwaard, W. (2010). Safety metaphors and theories, a review of the occupational safety literature of the US, UK and The Netherlands, till the first part of the 20th century. *Safety Science*, *48*(8), 1000–1018. http://doi.org/10.1016/j.ssci.2010.01.020

Swuste, P., Theunissen, J., Schmitz, P., Reniers, G., & Blokland, P. (2016). Process safety indicators, a review of literature. *Journal of Loss Prevention in the Process Industries*, *40*, 162–173. http://doi.org/10.1016/j.jlp.2015.12.020

Tan, J., & Wang, L. (2010). Flexibility–efficiency tradeoff and performance implications among Chinese SOEs. *Journal of Business Research*, *63*(4), 356–362. http://doi.org/10.1016/j.jbusres.2009.04.016

Teo, E., & Ling, F. (2006). Developing a model to measure the effectiveness of safety management systems of construction sites. *Building and Environment*, *41*(11), 1584–1592. http://doi.org/10.1016/j.buildenv.2005.06.005

Toellner, J. (2001). Improving Safety & Health Performance: Identifying & Measuring Leading Indicators. *Professional Safety*, *46*(9), 42–47.

Tomas, J. M., Melia, J. L., & Oliver, A. (1999). A cross-validation of a structural equation model of accidents: Organizational and psychological variables as predictors of work safety. *Work & Stress*, *13*(1), 49–58. http://doi.org/10.1080/026783799296183

Törner, M., & Pousette, A. (2009). Safety in construction - a comprehensive description of the characteristics of high safety standards in construction work, from the combined perspective of supervisors and experienced workers. *Journal of Safety Research*, *40*(6), 399–409. http://doi.org/10.1016/j.jsr.2009.09.005

Visser, K. (1998). Developments in HSE management in oil and gas exploration and production. *Safety Management, The Challenge of ChangePergamon, Amsterdam*, pp. 3–66.

Wang, F., Ding, L., Love, P. E. D., & Edwards, D. J. (2016). Modeling tunnel construction risk dynamics: Addressing the production versus protection problem. *Safety Science*, *87*, 101–115. http://doi.org/10.1016/j.ssci.2016.01.014

Wilson, H. (1989). Organisational behaviour and safety management in the construction industry. *Construction Management and Economics*, *7*, 303–319.

Wu, W., Gibb, A. G. F., & Li, Q. (2010). Accident precursors and near misses on construction sites: An investigative tool to derive information from accident databases. *Safety Science*, *48*(7), 845–858. http://doi.org/10.1016/j.ssci.2010.04.009

Wu, X., Liu, Q., Zhang, L., Skibniewski, M. J., & Wang, Y. (2015). Prospective safety performance evaluation on construction sites. *Accident Analysis & Prevention*, *78*, 58–72. http://doi.org/10.1016/j.aap.2015.02.003

Xinyu Huang, & Hinze, J. (2006). Owner's Role in Construction Safety. *Journal of Construction Engineering & Management*, *132*(2), 164–173. http://doi.org/10.1061/(ASCE)0733-9364(2006)132:2(164)

Yang, H., Chew, D. A. S., Wu, W., Zhou, Z., & Li, Q. (2012). Design and implementation of an identification system in construction site safety for proactive accident prevention. *Accident Analysis & Prevention*, *48*, 193–203. http://doi.org/10.1016/j.aap.2011.06.017

Yoon, S. J., Lin, H. K., Chen, G., Yi, S., Choi, J., & Rui, Z. (2013). Effect of Occupational Health and Safety Management System on Work-Related Accident Rate and Differences of Occupational Health and Safety Management System Awareness between Managers in South Korea's Construction Industry. *Safety and Health at Work*, *4*(4), 201–209. http://doi.org/10.1016/j.shaw.2013.10.002

Yung, P. (2009). Institutional arrangements and construction safety in China: an empirical examination. *Construction Management & Economics*, *27*(5), 439–450. http://doi.org/10.1080/01446190902855633

Zhou, Z., Goh, Y. M., & Li, Q. (2015). Overview and analysis of safety management studies in the construction industry. *Safety Science*, *72*(0), 337–350. http://doi.org/10.1016/j.ssci.2014.10.006

Zou, P., Chen, Y., & Chan, T. (2010). Understanding and Improving Your Risk Management Capability: Assessment Model for Construction Organizations. *Journal of Construction Engineering and Management*, *136*(8), 854–863. http://doi.org/10.1061/(ASCE)CO.1943-7862.0000175

Appendices and tables

Appendix A-1. Template to be filled out CONSRAT

Item Number **Classification of items. Rating level. Scoring criteria.**

I. General information and organizational factors

i. Identification dates

1. **Identifier**: nº_____, address____________________________
2. **Company name** ____
Contractor, or subcontractor in the case that the contractor does not have workers on site
In case of some contractors or subcontractors. chose:
The bigger one, with more of its own workers on site.
The principal (that has subcontractors).
3. **TIN**__________________
Of the company selected in item 2
4. **Date of the visit to the site**________

ii. Construction site characterisation

5. **General characterisation.** Rating: **1**☐**2**☐ Scoring: See App. B
1 - New construction
2 **-** Reform and extensions. Others Works at existing building
6. **Building Configuration.** Rating: **1**☐**2**☐**3**☐**4**☐**5**☐**6**☐ Scoring: See App. B
1- Isolated Single family house
2 - Infill single family house
3 - Services Building
4 - Isolated multi-family
5 - Infill multi-family
6 - Other uses
7. **Number of floors.** Rating: **1**☐**2**☐**3**☐**4**☐**5**☐ Scoring: See App. B
1- Ground floor (GF)
2 - GF+1-2
3 - GF+3-5
4 - GF+5
5 - Infrastructure
8. **Procedure construction typology.** Rating: **1**☐**2**☐ Scoring (0-1)
1 **-** Traditional. Conventional construction methodologies, systems, resources and materials
2 **-** Alternative. Unconventional procedures, systems or resources (prefabrication, slenderness, etc.)
9. **Administrative documentation.** Rating: **1**☐**2**☐ Scoring (0-1)
1 **-** Minor work. Construction site without technical project
2 **-** Major work. Construction site with technical project

ii. a. Stage of the work

10. **Main work stage.** Rating: **1**☐**2**☐**3**☐**4**☐**5**☐**6**☐**7**☐**8**☐**9**☐ Scoring: See App. B
1 - Interior works
2 - Installations
3 - Brickwork
4 - Flat roof
5 - Facade works
6 - Pitched roof
7 - Excavation
8 - Foundation and structure
9 - Demolitions
11. **Secondary work stage.** Rating: **1**☐**2**☐**3**☐**4**☐**5**☐**6**☐**7**☐**8**☐**9**☐ Scoring: See App. B
1 - Interior works
2 - Installations
3 - Brickwork
4 - Flat roof
5 - Facade works
6 - Pitched roof
7 - Excavation
8 - Foundation and structure
9 – Demolitions

12. **Number of works.** Rating: **1**☐**2**☐ Scoring (0-1)
1 - One main work
2 - More than one work
13. **Employer location assignments.** Rating: **1**☐**2**☐**3**☐**4**☐**5**☐**6**☐**7**☐**8**☐**9**☐ Scoring: See App. B
Where are most of the workers at the main work on site?
1 - On the field
2 - Interior floor
3 - Perimeter floor or roof
4 - On the floor at auxiliary resources in use
5 - Outdoor, on machine in use
6 - Outdoor, on auxiliary resources in use (platform, scaffold)
7 - Outdoor, on auxiliary resources to set up
8 - On machine or installation to set up

iii. Promoter characterisation

14. **Type of promoter.** Rating: **1**☐**2**☐**3**☐ Scoring: See App. B
1 - Private/Individual promoter
2 - Professional
3 - Public/Official administration
15. **Designation of health and safety coordinator.** Rating: **1**☐**2**☐ Scoring: See App. B
1 - No. There isn't any document to demonstrate the designation
2 - Yes. It's documented at construction site (incidents book, any documentation of administration or professional college)
16. **Documented work of the H&S coordinator.** Rating: **1**☐**2**☐**3**☐ Scoring: See App. B
1 - No/there is not datum. There is not evidences or nobody now
2 - Yes, but not systematic. There are some documentation instructions at any format
3 - Yes, systematic at incidents book
17. **Type of contracting.** Rating: **1**☐**2**☐ Scoring: See App. B
Number of construction firms that contract directly with the promoter
1 - Only one contractor
2 - Some contractors
18. **Special environmental conditions.** Rating: **1**☐**2**☐ Scoring: See App. B
1 - No
2 - Interferences like: Electrical, public spaces, streets or buildings at perimeters or party walls, slopes or evenness, etc.
19. **Locality. Municipal term ____________________**

iv. Constructor characterisation

20. **Type of constructor.** Rating: **1**☐**2**☐**3**☐ Scoring: See App. B
Selected at item two
1 - Self-employed
2 - Self-employed with workers at his charge
3 - Company (SA,SL,COP, UTE)
21. **Constructor's Role.** Rating: **1**☐**2**☐**3**☐ Scoring: See App. B
Selected at item two
1 - Subcontractor
2 - Contractor
3 - Promoter-constructor
22. **Number of companies at construction site____________**
Total number, including all companies and self-employed workers
23. **Subcontracting.** Rating: **1**☐**2**☐ Scoring (0-1)
Is there subcontracting on site?
1 - No
2 **–** Yes
24. **Level of subcontracting.** Rating: **1**☐**2**☐**3**☐ Scoring: See App. B
1 - Contractor (no subcontracting)
2 - First level of subcontracting
3 - Second level of subcontracting
25. **Control and register of subcontracting.** Rating: **1**☐**2**☐**3**☐ Scoring (0-0.5-1)
Is there a subcontracting book, if it is required
1 - Not required
2 - Yes

3 – No

26. **Number of workers of constructor on site**__________
Of the constructor selected at item two. The most important contractor or subcontractor

27. **Total number of workers on site** __________
All workers from all companies and self-employed workers

28. **Site management structure.** Rating: **1☐2☐3☐4☐5☐6☐** Scoring: See App. B
Refers to site structure, explained by the interviewee on the visit with regular presence and assistance to the construction site.
1 - Nobody in charge
2 - Worker with some functions
3 - Site foreman
4 - Business owner
5 - Site foreman and site manager
6 - Site foreman, site manager and prevention technical

29. **Preventive functions of the structure.** Rating: **1☐2☐3☐4☐** Scoring: See App. B
This means the level of knowledge and implication in prevention
1 - It's not assumed, there isn't nobody in charge of preventive topic
2 - It's assumed but on secondary way
3 - It's assumed within with principal activity
4 - It's assumed and documented in an organised way

30. **Preventive resource.** Rating: **1☐2☐3☐** Scoring (0-0.5-1)
1 - Nobody/ does not apply
2 - Assigned to a worker
3 **-** Assigned to one site foreman or qualified technician

v. Health and safety plan adequacy

31. **Presence at construction site of H&S plan.** Rating: **1☐2☐** Scoring: See App. B
Is the document physically at the construction site?
1 - No
2 – Yes

32. **Appropriateness of the previsions of the H&S plan**. Rating: **1☐2☐3☐4☐**Scoring: See App. B
The question refers to the general conditions and specific conditions of the current phase of the site at the time of the visit
1 - There isn't H&S plan or its previsions are unknown. Interlocutors at site don't know anything of contents of H&S plan
2 - The previsions in H&S plan aren't applicable to the site or there are critical mistakes.
3 - Appropriate previsions, no critical mistake. Possible errors don't affect systems and general protections, personal protection equipment (PPE) or collective protection (CP) specifically for the stage when they protect for serious risk
4 - Complete and appropriate in previsions. No deficiency

II. Risk factors on site

i. Health and safety plan compliance

33. **Compliance with the H&S plan or regulations in case.** Rating: **0☐1☐2☐3☐.** Scoring: See general valuation
0 Full and appropriate compliance. The phase is compliant with the H&S plan or general and specific regulations (implantation, circulations, CP, PPE)
1 Appropriate, no critical mistakes. Possible failure but it does not affect systems and general protections, personal protection equipment (PPE) or collective protection (CP) specifically for a phase where they protect against serious risk
2 Deficient, with critical mistakes. The H&S plan or regulations fail to affect systems and general protections, personal protection equipment (PPE) or collective protection (CP) with serious risk
3 Nothing, very deficient failure. There is no record of compliance with any aspect of the H&S plan or regulations

ii. General conditions valuation

34. **Construction fence. 0☐1☐2☐3☐**. Rating and scoring: See general valuation
35. **Circulations/order and tidiness/Illumination. 0☐1☐2☐3☐**. Rating and scoring: See general valuation
36. **Safety signage. 0☐1☐2☐3☐**. Rating and scoring: See general valuation

37. **Safety of electrical installation and cable. 0☐1☐2☐3☐**. Rating and scoring: See general valuation
38. **General collective protections. 0☐1☐2☐3☐**. Rating and scoring: See general valuation

iii. Stage conditions valuation
iii. a. Access

39. **Access. 0☐1☐2☐3☐**. Rating and scoring: See general valuation
This refers to the main stage or workplace, independently of general circulation conditions

iii. b. Falls from height

40. **Height of fall.** Rating: **0☐1☐2☐3☐**. Scoring: See general valuation
This refers to the primary phase or workplace
0 There is no height or it is controlled. There is no exposure or it is controlled by a preventive system, design, work stage, etc.
1 From 0 to 2 metres (exclusive)
2 From 2 to 6 metres (exclusive)
3 More than 6 metres
41. **Level of failure.** Rating: **0☐1☐2☐3☐**. Scoring: See general valuation
0 Complete appropriate. Risks are controlled by forecasted resources
1 Appropriate, without critical failures. There are minor failures, but with overall compliance with the conditions
2 Deficient, with critical failures. Important failures of protection systems that could affect the safety of users or of protection
3 Very deficient. There is no protection system or it is very deficient, it may create a false perception of protection increasing risk
42. **Continuity of exposure.** Rating: **0☐1☐2☐3☐**. Scoring: See general valuation
0 None, controlled or there is no exposure
1 Punctual or sporadic
2 At some stages of the process
3 Permanent
43. **Probability.** Rating: **0☐1☐2☐3☐**. Scoring: See general valuation
0 Very low probability
1 Low probability
2 Medium Probability
3 High Probability
44. **Severity.** Rating: **0☐1☐2☐3☐**. Scoring: See general valuation
0 No severity
1 Minor, slight injury
2 Medium, serious injury
3 Severe, serious injury or frequent death
45. **Intervention required.** Rating: **0☐1☐2☐3☐**. Scoring: See general valuation
0 Intervention is not necessary
1 No critical improvements are necessary
2 Corrections and critical improvements are necessary
3 Immediate intervention is necessary

iii. c. Other risks concurrence. In general 1= No risk, 2=Yes, there is risk.

46. **Falls on the same level/Slip.** Rating and scoring: See dichotomist valuation
47. **Fall of objects.** Rating and scoring: See dichotomist valuation
48. **Collapses or cave-ins.** Rating and scoring: See dichotomist valuation
49. **Cuts, hits, pricks.** Rating and scoring: See dichotomist valuation
50. **Hit by a vehicle, crushing, entrapment.** Rating and scoring: See dichotomist valuation
51. **Projections.** Rating and scoring: See dichotomist valuation
52. **Burns.** Rating and scoring: See dichotomist valuation
53. **Electricity contact shock.** Rating and scoring: See dichotomist valuation
54. **Overexertion.** Rating and scoring: See dichotomist valuation
55. **Hygienic risk exposure.** Rating and scoring: See dichotomist valuation
56. **Other risks.** (Hygienic, prick with connecting rod, electrical interferences). Rating and scoring: See dichotomist valuation
57. **Incidence of falls from height risk.** Rating: **0☐1☐2☐3☐**. Scoring: See general valuation
0 None
1 Punctual or sporadic
2 Occasional occurrence, sometimes

3 Permanent

iii. d. Process valuation

58. **Type of process.** Rating: **1☐2☐.** Scoring: See dichotomist valuation
1 Traditional. The sequence and resources involved in the activities are common at construction sites
2 Not traditional. Sequence, resources or construction systems are not common or habitual
59. **Adequacy of the process.** Rating: **0☐1☐2☐3☐**. Scoring: See general valuation
0 Very appropriate. The sequence of operations and resources and resources provided in the H&S plan are adapted to the site typology as needed
1 Appropriate for site conditions. Some dysfunction in the process is possible, but globally the process is appropriate
2 Inappropriate for site conditions. The process is not appropriate for the phase or the construction site
3 Nothing or inappropriate. Process is completely inappropriate for construction site
60. **Process deviation.** Rating: **0☐1☐2☐3☐**. Scoring: See general valuation
0 There are no deviations. It is complying with the process forecast in the H&S plan
1 There are some deviations, but they are not critical. It is mostly complying with the process forecast in the H&S plan
2 There are critical deviations. There are some critical deviations in the forecast process
3 There are critical and permanent deviations. The deviations are important and continuous

iii. e. Collective protections. CP.

61. **Scaffolds. Adjustment to the phase.** Rating and scoring: See dichotomist valuation
62. **Scaffolds. Installation validation. 0☐1☐2☐3☐**. Rating and scoring: See general valuation
63. **Safety nets. Adjustment to the phase.** Rating: **1☐2☐**. Scoring: See dichotomist valuation
0 Appropriate. It is the CP necessary for the work stage and the risks.
1 Inappropriate. It is not an appropriate CP for the work stage and the risks or typology of the site.
64. **Safety nets. Installation validation. 0☐1☐2☐3☐**. Rating and scoring: See general valuation
65. **Railing. Adjustment to the phase.** Rating and scoring: See dichotomist valuation
66. **Railing. Installation validation. 0☐1☐2☐3☐**. Rating and scoring: See general valuation
67. **Safety boarded. Adjustment to the phase.** Rating and scoring: See dichotomist valuation
68. **Safety boarded. Installation validation. 0☐1☐2☐3☐**. Rating and scoring: See general valuation
69. **Number of items CP**: **0☐1☐2☐3☐4☐5☐6☐7☐8☐**
70. **Need for more CP specific to the phase.** Rating: **1☐2☐**. Scoring: See dichotomist valuation
1 No, it is not necessary. It is enough that they are installed, independently of the adjustment
2 Yes, more CP is needed, in addition to that which is already installed

iii. f. Personal protection equipment. PPE

71. **Fall protection system. Adjustment to the phase.** Rating: **1☐2☐**. Scoring: See dichotomist valuation
1 Appropriate. The system is adapted to the edge that needs protected (harness, connector, lifeline, anchorage) Independently from the installation
2 Not adapted. The fall protection system is not adapted to the edge or there is no protection system.
72. **Fall protection system. Installation validation.** Rating and scoring: See dichotomist valuation
73. **Number of PPE items: 0☐1☐2☐**
74. **Need for more PPE specific to the phase.** Rating: **1☐2☐**. Scoring: See dichotomist valuation
1 No, it is not necessary. It is enough that they are installed, independently of the adjustment
2 Yes, more CP is needed, in addition to that which is already installed

iv. Auxiliary resources and machinery

iv. a. Auxiliary resources

75. **Scaffolds. Adjustment to the phase.** Rating and scoring: See dichotomist valuation
76. **Scaffolds. Installation validation. 0☐1☐2☐3☐**. Rating and scoring: See general valuation
77. **Suspended scaffolds. Adjustment to the stage.** Rating and scoring: See dichotomist valuation
78. **Suspended scaffolds. Installation validation. 0☐1☐2☐3☐**. Rating and scoring: See general valuation
79. **Horse scaffolds/work platform. Adjustment to the phase.** Rating and scoring: See

dichotomist valuation

80. **Horse scaffolds/work platform. Installation validation.** Rating and scoring: See dichotomist valuation
81. **Portable ladders. Adjustment to the phase.** Rating and scoring: See dichotomist valuation
82. **Portable ladders. Installation validation. 0☐1☐2☐3☐**. Rating and scoring: See general valuation
83. **Other. Adjustment to the phase.** Rating and scoring: See dichotomist valuation
84. **Other resources. Installation validation. 0☐1☐2☐3☐**. Rating and scoring: See general valuation
85. **Number of AR items: 0☐1☐2☐3☐4☐5☐**

iv. b. Elevation resources

86. **Forklift truck/dumbwaiter. Adjustment to the phase.** Rating and scoring: See dichotomist valuation
87. **Forklift truck. Installation validation. 0☐1☐2☐3☐**. Rating and scoring: See general valuation
88. **Crane truck. Adjustment to the phase.** Rating and scoring: See dichotomist valuation
89. **Crane truck. Installation validation. 0☐1☐2☐3☐**. Rating and scoring: See general valuation
90. **Fall protection system for elevation work resources.** Rating and scoring: See dichotomist valuation
91. **Auxiliary resources for elevation system**. **0☐1☐2☐3☐**. Rating and scoring: See general valuation
    (Supporting cable, operating ropes, unloading platforms, etc.)
92. **Number of ME items: 0☐1☐2☐3☐4☐**

iv. c. Other machinery

93. **Concrete mixer. Adjustment to the phase.** Rating and scoring: See dichotomist valuation
94. **Concrete mixer. Installation validation. 0☐1☐2☐3☐**. Rating and scoring: See general valuation
95. **Manual tool. Adjustment to the phase. 1☐2☐**. Rating and scoring: See dichotomist valuation
96. **Manual tool. Installation validation. 0☐1☐2☐3☐**. Rating and scoring: See general valuation
97. **Number of OM items: 1☐2☐**

Valuation criteria to fill the form

General Valuation criteria

Rating	Criteria	Scoring
0.	Complete and appropriate. It is well installed, reliable, independent for the worker that used it	0
1.	Appropriate, without critical failures. There are some minor failures, but in overall compliance with the conditions	0.33
2.	Deficient, with critical failures. Failures are significant and could affect safety resources, installation or the user or other persons in a partial way	0.66
3.	Very deficient. There are no resources or failures are significant and are affecting safety resources, installation, the users or other persons in a continuous way	1.00

Dichotomous valuation criteria

Rating	Criteria	Scoring
1.	Adequate for the work, construction phase or type	0
2.	Not adequate for the work, construction phase or type	1

Appendix B-1. Organisational variables, items composition, rating scales, scoring and aggregation rules

Variable	Item composition and rating scales[1]	Item scoring[2]	Variable aggregation rules
OV1. Complexity of project	**General characterization.**		Mean
	- New construction	0	
	- Reform and extensions. Others Works at existing building	1	
	Building Configuration.		
	- Isolated Single family house	0	
	- Infill single family house	0.2	
	- Services Building	0.4	
	- Isolated multi-family	0.6	
	- Infill multi-family	0.8	
	- Other uses	1	
	Special environment conditions.		
	- No	0	
	- Interferences like: Electrical, public spaces, streets or buildings at perimeters or party walls, slopes or evenness, etc.	1	
OV2. Size of site	**Number of floors.**		Direct item scoring
	- Ground floor (GF)	0	
	- GF+1-2	0.25	
	- GF+3-5	0.50	
	- GF+5	0.75	
	- Infrastructure	1	
OV3. Stage characteristics	**Main work stag**e		Mean
	- Interior works	0	
	- Installations	0.125	
	- Brickwork	0.25	
	- Flat roof	0.375	
	- Facade works	0.50	
	- Pitched roof	0.625	
	- Excavation	0.75	
	- Foundation and structure	0.875	
	- Demolitions	1	
	Second work stage		
	- Interior works	0	
	- Installations	0.125	
	- Brickwork	0.25	
	- Flat roof	0.375	
	- Facade works	0.50	
	- Pitched roof	0.625	
	- Excavation	0.75	
	- Foundation and structure	0.875	
	- Demolitions	1	
OV4. Promoter resources	**Type of promoter firm resources**		Direct item scoring
	- Private/Individual promoter	0	
	- Professional	0.5	
	- Public/Official administration	1	
OV5. Constructor resources	**Type of construction firm resources**		Mean
	- Self-employed	0	
	- Self-employed with workers at his charge	0.5	
	- Company (SA,SL,COP, UTE)	1	
	Resources depending of Constructor's Role		
	- Subcontractor	0	
	- Contractor	0.5	
	- Promoter-constructor	1	
	Site management structure		
	- Nobody in charge	0	
	- Worker with some functions	0.2	
	- Site foreman	0.4	
	- Business owner	0.6	

Variable	Item composition and rating scales[1]	Item scoring[2]	Variable aggregation rules
	- Site foreman and site manager	0.8	
	- Site foreman, site manager and prevention technical	1	
OV6. Internal organization structure	**Type of contracting**.		Mean
	- Only one contractor	0	
	- Some contractors	1	
	Number of companies at construction site		
	- Just 1	0	
	- From 2 to 3	0.33	
	- From 4 to 6	0.66	
	- More than 6	1	
	Level of subcontracting		
	- Contractor (no subcontracting)	0	
	- First level of subcontracting	0.5	
	- Second level of subcontracting	1	
OV7. Job planning and design	**Number of woks**		**Mean**
	- One main work	0	
	- More than one work	1	
	Employer location assignments		
	- On the field	0	
	- Interior floor	0.1425	
	- Perimeter floor or roof	0.285	
	- On the floor at auxiliary resources in use	0.4275	
	- Outdoor, on machine in use	0.57	
	- Outdoor, on auxiliary resources in use (platform, scaffold)	0.7125	
	- Outdoor, on auxiliary resources to set up	0.855	
	- On machine or installation to set up	1	
	Total number of workers at site		
	- To 3	0	
	- From 4 to 6	0.2	
	- From 7 to 10	0.4	
	- From 10 to 20	0.6	
	- From 20 to 30	0.8	
	- More than 30	1	
	Ratio of number of workers of principal constructor over total workers at site		
	- Less than 0.25	0	
	- From 0.25 to 0.5	0.25	
	- From 0.5 to 0.75	0.5	
	- More than 0.75	1	
OV8. Coordination resources	**Designation Health and safety coordinator**		Mean
	- No. There isn't any document to demonstrate the designation	0	
	- Yes. It's documented at construction site (incidents book, any documentation of administration or professional college)	1	
OV9. Preventive functions	**Documented work H&S coordinator**		Mean
	- No/there is not datum. There is not evidences or nobody now	0	
	- Yes, but not systematic. There are some documentation instructions at any format	0.5	
	- Yes, systematic at incidents book	1	
	Preventive functions of the structure		
	- It's not assumed, there isn't nobody in charge of preventive topic	0	
	- It's assumed but on secondary way	0.33	
	- It's assumed within with principal activity	0.66	
	- It's assumed and documented in an		

Variable	Item composition and rating scales[1]	Item scoring[2]	Variable aggregation rules
	organised way	1	
OV10. Health and Safety Plan	**Presence at construction site of H&S plan** - No - Yes **Appropriateness of H&S plan's previsions**. - There isn't H&S plan or its previsions are unknown. Interlocutors at site don't know anything of contents of H&S plan - The previsions in H&S plan aren't applicable to the site or there are critical mistakes. - Appropriate previsions, no critical mistake. Possible errors don't affect systems and general protections, personal protection equipment (PPE) or collective protection (CP) specifically for the stage when they protect for serious risk - Complete and appropriate in previsions. No deficiency	 0 1 0 0.33 0.66 1	Mean

[1] Higher values in any scale signal more complexity and more resources. [2] Item scales: from 0 to 1, where 0 means less complexity or resources, and 1 the maximum level of complexity or resources.

Appendix C-1. Risk variables item composition and aggregation rules

Variable	Item composition	Item scoring[1]	Variable aggregation rules
RV1. Health and Safety Plan *	- Compliance with the H&S plan or regulations in case.	0 - 0.33 - 0.66 - 1.00	Direct item scoring
RV2. General conditions	- Construction fence - Circulations/order and tidiness/Illumination - Safety signage - Safety of electrical installation and cable	0 - 0.33 - 0.66 - 1.00 0 - 0.33 - 0.66 - 1.00 0 - 0.33 - 0.66 - 1.00 0 - 0.33 - 0.66 - 1.00	Mean
RV3. Collective protections*****	General collective protections	0 - 0.33 - 0.66 - 1.00	Direct item scoring
RV4. Access	Access	0 - 0.33 - 0.66 - 1.00	Direct item scoring
R5. Falls of height	- Height of fall - Level of failure - Continuation of exposure - Probability - Severity - Intervention required	0 - 0.33 - 0.66 - 1.00 0 - 0.33 - 0.66 - 1.00 0 - 0.33 - 0.66 - 1.00 0 - 0.33 - 0.66 - 1.00 0 - 0.33 - 0.66 - 1.00 0 - 0.33 - 0.66 - 1.00	Mean
RV6. Other risks	- Falls on the same level/Slip - Fall of objects - Collapses or cave-ins - Cuts, hits, pricks - Hit by a vehicle, crushing, entrapment, projections - Burns. - Electricity contact shock - Overexertion - Hygienic risk exposure - Other risks - Incidence of falls from height risk	0 - 1 0 - 1 0 - 1 0 - 1 0 - 1 0 - 1 0 - 1 0 - 1 0 - 1 0 - 1 0 - 0.33 - 0.66 - 1.00	Mean between the percentage of identified risks items and incidence of falls item
RV7. Process	- Adequacy of the process - Process deviation	0 - 0.33 - 0.66 - 1.00 0 - 1	Mean
RV8. Collectives protection*****	For each protection: - Adjustment to the phase - Installation validation In general: - Need for more CP specific to the phase	 0 - 1 0 - 0.33 - 0.66 - 1.00 0 - 1	Mean of adjustments and installations. Choose the highest value between these two means and the need for more CP
RV9. Personal protection*****	For each fall protection system: - Adjustment to the phase - Installation validation - Need for more PPE specific to the phase	 0 - 1 0 - 0.33 - 0.66 - 1.00 0 - 1	Mean of adjustments and installations. Choose the highest value between these two means and the need for more PEE
RV10. Auxiliary resources and machinery	For each resource and machinery: - Adjustment to the phase - Installation validation	 0 - 1 0 - 0.33 - 0.66 - 1.00	Mean of adjustments and installations. Choose the highest value between them

*Alarm Variables. [1] Item scales: from 0 to 1, where 0 means less complexity or resources, and 1 the maximum level.

Appendix A-2. Classification of items' answers attend complexity and resources.

Factor	Variable	Item	Scales
F1. Site complexity	OV1. Complexity of project	**1.-General characterization.**	
		New construction	1
		Reform and extensions. Others Works at existing building	2
		2.-Building Configuration.	
		Isolated single family house	1
		Infill single family house	2
		Services building	3
		Isolated multi-family	4
		Infill multi-family	5
		Other uses	6
		3.-Special environment conditions.	
		No	1
		Interferences like: Electrical, public spaces, streets or buildings at perimeters or party walls, slopes or evenness, etc.	2
	OV2. Size of site	**4.- Number of floors.**	
		Ground floor (GF)	1
		GF+1-2	2
		GF+3-5	3
		GF+5	4
		Infrastructure	5
	OV3. Stage characteristics	**5.-Main work stage**	
		Interior works	1
		Installations	2
		Brickwork	3
		Flat roof	4
		Outdoor works (faces)	5
		Pitched roof	6
		Excavation	7
		Foundation and structure	8
		Demolitions	9
		6.-Second work stage	
		Interior works	1
		Installations	2
		Brickwork	3
		Flat roof	4
		Outdoor works (faces)	5
		Pitched roof	6
		Excavation	7
		Foundation and structure	8
		Demolitions	9
F2.Firm's structure resources	OV4. Promoter resources	**7.- Type of promoter firm resources**	
		1 Private/particular promoter	1
		2 Professional	2
		3 Public/Official administration	3
	OV5. Constructor resources	**8.- Type of construction firm resources**	
		Selected at item two	
		Self-employed	1
		Self-employed with workers at his charge	2
		Company (SA,SL,COP, UTE)	3
		9.- Resources depending of Constructor's Role	
		Selected at item two	
		Subcontractor	1
		Contractor	2
		Promoter-constructor	3
		10.- Site management structure	
		It's referent to site structure, explained by the interviewee at visit with regularly presence and assistance to the construction site.	
		Nobody in charge	1
		Worker with some functions	2
		Site foreman	3
		Business owner	4
		Site foreman and site manager	5
		Site foreman, site manager and prevention technical	6
F3. Site structure Complexity	OV6A. Internal organization structure	**11.-Type of contracting**.	
		Number of construction firms that has direct contracting with promoter	
		Only one contractor	1
		Some contractors	2

Factor	Variable	Item	Scales
	OV6. Internal organization structure	**12.- Number of companies at construction site**	
		Total number, including all companies and self-workers	
		1 Just 1	1
		2 From 2 to 3	2
		3 From 4 to 6	3
		4 More than 6	4
		13.- Level of subcontracting	
		0 Contractor (no subcontracting	1
		1 First level of subcontracting	2
		2 Second level of subcontracting	3
	OV7. Job planning and design	**14.- Number of woks**	
		1 One main work	1
		2 More than one work	2
		15.- Employer location assignments	
		Where are most of the workers at the main work site?	
		1 On the field	1
		2 Interior floor	2
		3 Perimeter floor or roof	3
		8 On the floor at auxiliary resources in use	4
		6 Outdoor, on machine in use	5
		4 Outdoor, on auxiliary resources in use (platform, scaffold)	6
		5 Outdoor, on auxiliary resources to set up	7
		7 On machine or installation to set up	8
		16.- Total number of workers at site	
		All works from all companies and self-workers	
		To 3	1
		From 4 to 6	2
		From 7 to 10	3
		From 10 to 20	4
		From 20 to 30	5
		More than 30	6
		17.- Ratio of number of workers of principal constructor over total workers at site	
		Less than 0.25	1
		From 0.25 to 0.5	2
		From 0.5 to 0.75	3
		More than 0.75	4
F4. Safety management resources	OV8. Coordination resources	**18.- Designation Health and safety coordinator**	
		No. There isn't any document to demonstrate the designation	1
		Yes. It's documented at construction site (incidents book, any documentation of administration or professional college)	2
	OV9. Preventive functions	**19.- Documented work H&SC**	
		No/there is not datum. There is not evidences or nobody now	1
		Yes, but not systematic. There are some documentation instructions at any format	2
		Yes, systematic at incidents book	3
		20.- Preventive functions of the structure	
		It means the level of knowledge and implication in preventive topic	
		It's not assumed, there isn't nobody in charge of preventive topic	1
		It's assumed but on secondary way	2
		It's assumed within with principal activity	3
		It's assumed and documented in an organised way	4
	OV10. Health and safety plan	**21.- Presence at construction site of H&SP**	
		Is it physically the document at construction site?	
		No	1
		Yes	2
		22.-Appropriateness of H&SP's previsions.	
		The question is referent to general conditions and specific conditions to actual stage of the site at the visit moment	
		There isn't H&SP or its previsions are unknown. Interlocutors at site don't know anything of contents of H&SP	1
		The previsions in H&SP aren't applicable to the site or there are critical mistakes.	2
		Appropriate previsions, no critical mistake. Possible errors don't affect systems and general protections, personal protection equipment (PPE) or collective protection (CP) specifically for the stage when they protect for serious risk	3
		Complete and appropriate in previsions. No deficiency	4

Appendix B-2. Risk variables composition and assessment scale

Risk Variable	Items and rating
RV1.- Health and safety plan	**1.** Compliance with the H&SP or regulations in case. Rating: 0☐1☐2☐3☐. Scoring: see Four level scale at the end of this table (see Four level scale) 0 Full and appropriate compliance. The phase is compliant with the H&SP or general and specific regulations (implantation, circulations, CP, PPE) 1 Appropriate, no critical mistakes. Possible failure but it does not affect systems and general protections, personal protection equipment (PPE) or collective protection (CP) specifically for a phase where they protect against serious risk 2 Deficient, with critical mistakes. The H&SP or regulations fail to affect systems and general protections, personal protection equipment (PPE) or collective protection (CP) with serious risk 3 Nothing, very deficient failure. There is no record of compliance with any aspect of the H&SP or regulations
RV2.- General conditions	**2.** Construction fence. Rating: 0☐1☐2☐3☐ See Four level scale **3.** Circulations/order and tidiness/Illumination. Rating: 0☐1☐2☐3☐ See Four level scale **4.** Safety signage. Rating: 0☐1☐2☐3☐ See Four level scale **5.** Safety of electrical installation and cable. Rating: 0☐1☐2☐3☐ See Four level scale
RV3.- Collective protections	**6.** General collective protections. Rating: 0☐1☐2☐3☐ See Four level scale
RV4.- Access **RV5.- Falls of height**	**7.** Access. Rating: 0☐1☐2☐3☐. See Four level scale This refers to the main stage or workplace, independently of general circulation conditions **8.** Height of fall. Rating: 0☐1☐2☐3☐. Scoring: see Four level scale This refers to the primary phase or workplace 0 There is no height or it is controlled. There is no exposure or it is controlled by a preventive system, design, work stage, etc. 1 From 0 to 2 metres (exclusive) 2 From 2 to 6 metres (exclusive) 3 More than 6 metres **9.** Level of failure. Rating: 0☐1☐2☐3☐. See Four level scale 0 Complete appropriate. Risks are controlled by forecasted resources 1 Appropriate, without critical failures. There are minor failures, but with overall compliance with the conditions 2 Deficient, with critical failures. Important failures of protection systems that could affect the safety of users or of protection 3 Very deficient. There is no protection system or it is very deficient, it may create a false perception of protection increasing risk **10.** Continuation of exposure. Rating: 0☐1☐2☐3☐. Scoring: see Four level scale 0 None, controlled or there is no exposure 1 Punctual or sporadic 2 At some stages of the process 3 Permanent **11.** Probability. Rating: 0☐1☐2☐3☐. Scoring: see Four level scale 0 Very low probability 1 Low probability 2 Medium Probability 3 High Probability **12.** Severity. Rating: 0☐1☐2☐3☐. Scoring: see Four level scale 0 No severity 1 Minor, slight injury 2 Medium, serious injury 3 Severe, serious injury or frequent death **13.** Intervention required. Rating: 0☐1☐2☐3☐. Scoring: see Four level scale 0 Intervention is not necessary 1 No critical improvements are necessary 2 Corrections and critical improvements are necessary 3 Immediate intervention is necessary
RV6.- Other risks	**14.** Falls on the same level/Slip. Rating 1☐2☐ Identifying risk: 1= No risk, 2=Yes, there is risk. Scoring: see Dichotomous scale at the end of this table (see Dichotomous scale) **15.** Fall of objects. Rating 1☐2☐ Identifying risk: 1= No risk, 2=Yes, there is risk. Scoring: see Dichotomous scale

Risk Variable	Items and rating
	16. Collapses or cave-ins. Rating 1☐2☐ Identifying risk: 1= No risk, 2=Yes, there is risk. Scoring: see Dichotomous scale **17.** Cuts, hits, pricks. Rating 1☐2☐ Identifying risk: 1= No risk, 2=Yes, there is risk. Scoring: see Dichotomous scale **18.** Accident by vehicle, crushing, entrapment. Rating 1☐2☐ Identifying risk: 1= No risk, 2=Yes, there is risk. Scoring: see Dichotomous scale **19.** Projections. Rating 1☐2☐ Identifying risk: 1= No risk, 2=Yes, there is risk. Scoring: see Dichotomous scale **20.** Burns. Rating 1☐2☐ Identifying risk: 1= No risk, 2=Yes, there is risk. Scoring: see Dichotomous scale **21.** Electricity contact shock. Rating 1☐2☐ Identifying risk: 1= No risk, 2=Yes, there is risk. Scoring: see Dichotomous scale **22.** Overexertion. Rating 1☐2☐ Identifying risk: 1= No risk, 2=Yes, there is risk. Scoring: see Dichotomous scale **23.** Intoxication. Rating 1☐2☐ Identifying risk: 1= No risk, 2=Yes, there is risk. Scoring: see Dichotomous scale **24.** Other risks. (Hygienic, prick with connecting rod, electrical interferences). Rating 1☐2☐ Identifying risk: 1= No risk, 2=Yes, there is risk. Scoring: see Dichotomous scale **25.** Incidence of falls from height risk. Rating: 0☐1☐2☐3☐. Scoring: see Four level scale 0 None 1 Punctual or sporadic 2 Occasional occurrence, sometimes 3 Permanent
RV7.- Process	**26.** Type of process. Rating: 1☐2☐. Scoring: see Dichotomous scale 1 Traditional. The sequence and resources involved in the activities are common at construction sites 2 Not traditional. Sequence, resources or construction systems are not common or habitual **27.** Adequacy of the process. Rating: 0☐1☐2☐3☐. Scoring: see Four level scale 0 Very appropriate. The sequence of operations and resources and resources provided in the H&SP are adapted to the site typology as needed 1 Appropriate for site conditions. Some dysfunction in the process is possible, but globally the process is appropriate 2 Inappropriate for site conditions. The process is not appropriate for the phase or the construction site 3 Nothing or inappropriate. Process is completely inappropriate for construction site **28.** Process deviation. Rating: 0☐1☐2☐3☐. Scoring: see Four level scale 0 There are no deviations. It is complying with the process forecast in the H&SP 1 There are some deviations, but they are not critical. It is mostly complying with the process forecast in the H&SP 2 There are critical deviations. There are some critical deviations in the forecast process 3 There are critical and permanent deviations. The deviations are important and continuous
RV 8.- Collectives protections	**29.** Scaffolds. Adjustment to the phase. Rating: de 1☐2☐. See Dichotomous scale **30.** Scaffolds. Installation validation. Rating: 0☐1☐2☐3☐. See Four level scale **31.** Safety nets. Adjustment to the phase. Rating: 1☐2☐. See Dichotomous scale for value 0 Appropriate. It is the CP necessary for the work stage and the risks. 1 Inappropriate. It is not an appropriate CP for the work stage and the risks or typology of the site. **32.** Safety nets. Installation validation. Rating: 0☐1☐2☐3☐. See Four level scale **33.** Railing. Adjustment to the phase. Rating: 1☐2☐. See Dichotomous scale **34.** Railing. Installation validation. Rating: 0☐1☐2☐3☐. See Four level scale **35.** Safety boarded. Adjustment to the phase. Rating: 1☐2☐. See Dichotomous scale **36.** Safety boarded. Installation validation. Rating: 0☐1☐2☐3☐. See Four level scale **37.** Need for more CP specific to the phase. Rating: 1☐2☐. See Dichotomous scale 1 No, it is not necessary. It is enough that they are installed, independently of the adjustment 2 Yes, more CP is needed, in addition to that which is already installed
RV9.- Personal protections	**38.** Fall protection system. Adjustment to the phase. Rating: 1☐2☐. See Dichotomous scale 1 Appropriate. The system is adapted to the edge that needs protected (harness, connector, lifeline, anchorage) Independently from the installation 2 Not adapted. The fall protection system is not adapted to the edge or there is no protection system. **39.** Fall protection system. Installation validation. Rating: 0☐1☐2☐3☐. See Four level scale **40.** Need for more PPE specific to the phase. Rating: 1☐2☐. See App.C 1 No, it is not necessary. It is enough that they are installed, independently of the adjustment

Risk Variable	Items and rating
	2 Yes, more CP is needed, in addition to that which is already installed
RV10. Auxiliary resources and machines	**41.** Scaffolds. Adjustment to the phase. Rating: 1☐2☐. See Dichotomous scale **42.** Scaffolds. Installation validation. Rating: 0☐1☐2☐3☐. See Four level scale **43.** Suspended scaffolds. Adjustment to the stage. Rating: 1☐2☐. See Dichotomous scale **44.** Suspended scaffolds. Installation validation. Rating: 0☐1☐2☐3☐. See Four level scale **45.** Horse scaffolds/work platform. Adjustment to the phase. Rating: de 1☐2☐. See Dichotomous scale **46.** Horse scaffolds/work platform. Installation validation. Rating: 0☐1☐2☐3☐. See Four level scale **47.** Portable ladders. Adjustment to the phase. Rating: 1☐2☐. See Dichotomous scale **48.** Portable ladders. Installation validation. Rating: 0☐1☐2☐3☐. See Four level scale **49.** Other resources. Adjustment to the phase. Rating: de 1☐2☐. See Dichotomous scale **50.** Other resources. Installation validation. Rating: 0☐1☐2☐3☐. See Four level scale **51.** Forklift truck/dumbwaiter. Adjustment to the phase. Rating: 1☐2☐. See Dichotomous scale **52.** Forklift truck. Installation validation. Rating: 0☐1☐2☐3☐. See Four level scale **53.** Crane truck. Adjustment to the phase. Rating: 1☐2☐. See Dichotomous scale **54.** Crane. Installation validation. Rating: 0☐1☐2☐3☐. See Four level scale **55.** Fall protection system for elevation work resources. Rating: 1☐2☐. See Dichotomous scale **56.** Auxiliary resources for elevation system. Rating: 0☐1☐2☐3☐. See Four level scale (Supporting cable, operating ropes, unloading platforms, etc.) **57.** Concrete mixer. Adjustment to the phase. Rating: 1☐2☐. See Dichotomous scale **58.** Concrete mixer. Installation validation. Rating: 0☐1☐2☐3☐. See Four level scale **59.** Manual tool. Adjustment to the phase. Rating: 1☐2☐. See Dichotomous scale **60.** Manual tool. Installation validation. Rating: 0☐1☐2☐3☐. See Four level scale

Levels of risk assessment

Four level scale

Level / Value	Meaning
1 = 0	Complete and appropriate. It is well installed, reliable, independent for the worker that used it
2 = 0.33	Appropriate, without critical failures. There are some minor failures, but in overall compliance with the conditions
3 = 0.66	Deficient, with critical failures. Failures are significant and could affect safety resources, installation or the user or other persons in a partial way
4 = 1.00	Very deficient. There are no resources or failures are significant and are affecting safety resources, installation, the users or other persons in a continuous way

Dichotomous scale

Level / Value	Meaning
1 = 0	Adequate for the work, construction phase or type
2 = 1	Not adequate for the work, construction phase or type

For further details consult the complete study of the tool (see Paper 1, chapter 1).

Appendix C-2. Summary statistic of OVs, RVs and SRI

OVs and RVs	N	Minimum	Maximum	Mean	S. e. of the mean	Standard deviation
OV 1.- Complexity of project	957	0.00	100.00	20.09	0.64	19.72
OV 2.- Size of site	957	0.00	93.31	55.79	0.44	13.45
OV 3.- Stage characteristics	957	0.00	100.00	15.62	0.65	20.10
OV 4.- Promoter resources	957	0.00	100.00	60.53	0.85	26.30
OV 5.- Constructor resources	957	4.67	86.72	42.58	0.52	15.96
OV 6.- Internal organization structure	957	0.00	100.00	20.09	0.64	19.72
OV 7.- Job planning and design	957	0.00	93.31	55.79	0.42	13.45
OV 8.- Coordination resources	957	0.00	100.00	15.62	0.65	20.10
OV 9.- Preventive functions	957	0.00	100.00	60.53	0.85	26.30
OV 10.- H&SP adequacy	957	4.67	86.72	42.58	0.52	15.96
RV 1.- H&S plan compliment	957	.33	1.00	.78	.006	.18
RV 2.- General conditions	957	.13	1.00	.67	.004	.13
RV 3.- Collective protections	957	.33	1.00	.78	.007	.20
RV 4.- Access	957	.33	1.00	.66	.006	.19
RV 5.- Falls from height	957	.11	1.00	.79	.006	.17
RV.6.- Other risks	957	.17	.96	.67	.005	.16
RV 7.- Process	957	.33	1.00	.77	.006	.20
RV 8.- Collectives protections	957	.00	1.00	.95	.006	.19
RV 9.- Personal protection equipment	957	.00	1.00	.76	.014	.42
RV 10.- Auxiliary resources and machinery	909	.33	1.00	.82	.006	.18
Site Risk Index (SRI)	957	.31	.99	.76	.004	.13

Appendix A-3. *ORGDES* composition

Control variable	CONSRAT Variable	Item	Importance Degree (SD)	Derived weight
ORGDES	OV1. Internal organization structure	1. Type of contracting	5.8 (0.87)	.36
		2. Number of companies	4.9 (1.29)	.30
		3. Level of subcontracting	5.4 (1.29)	.34
	OV2. Job planning and design	4. Number of woks	5.6 (1.03)	.27
		5. Employer location assignments	5.8 (0.87)	.28
		6. Total number of workers at site	4.9 (0.65)	.23
		7. Ratio of number of workers of principal constructor over total workers at site	4.7 (0.9)	.22

Table 5. Incidence of risk on site (*SRI*) on accident rate. (2004-2009)

Variables	Pooled (1)	Random effects (2)	Fixed effects (3)	Pooled (4)	Random effects (5)	Fixed effects (6)	Pooled (7)	Random effects (8)	Fixed effects (9)
SRI_t				0.215**	0.205**	0.247	0.219**	0.208**	0.2441511*
ORGDES	0.002**	0.002**	0.002	0.002**	0.002***	0.003*	0.002***	0.002***	0.0022704
Intercept	0.135***	0.126***	0.132***	-0.039	-0.040	-0.088	-0.015	-0.014	0.0048582
Year 2005							0.0245	0.024	0.0373536
Year 2006							-0.0455	-0.054	-0.1265998**
Year 2007							-0.0405	-0.0514	-.1368932**
Year 2008							-0.106**	-0.113**	-0.1840862***
Year 2009							-0.116**	-0.128**	-0.2825158
Goodness of fit	F(1, 360) = 4.77**	Wald chi2(1) = 6.40**	F(1,251) = 1.60	F(1, 353) = 5.40***	Wald chi2(2) = 12.18***	F(1,249) = 2.64*	F(7, 347) = 2.94***	Wald chi2(7)= 22.36***	F(7,249) = 2.44**
R-squared overall	0.008	0.011	0.008	0.020	0.020	0.020	0.048	0.047	0.0414
No. of observ.	355	355	355	355	355	355	355	355	355

SRI is index of risk on site; *ORGDES* is a level of complexity of site organizational design

* Significance level: $p < 0.1$.

** Significance level: $p < 0.05$.

*** Significance level: $p < 0.01$.

Table 6. - Incidence of risk on site (*SRI*) on accident rate. (2004-2007)

Variables	Pooled (1)	Random effects (2)	Fixed effects (3)	Pooled (4)	Random effects (5)	Fixed effects (6)	Pooled (7)	Random effects (8)	Fixed effects (9)
SRI_t				0.287***	0.287***	0.401**	0.293***	0.295***	0.342*
ORGDES	0. 002**	0.002***	0.006	0.002**	0.002***	0.003	0.002**	0.002***	0.002
Intercept	0. 142***	0.136***	0.152***	-0.087	-0.094	-0.184	-0.073	-0.078	0.079
Year 2005							0.024	0.026	0.107
Year 2006							-0.045	-0.055	-0.127**
Year 2007							-0.042	-0.056	-0.134**
Goodness of fit	F(1, 303) = 5.23**	Wald chi2(1) = 6.74***	F(1,220) = 1.07	F(2, 295) = 6.36***	Wald chi2(2) = 14.7***	F(1,217) = 3.54**	F(5, 292) = 2.71**	Wald chi2(5)= --	F(5,217) = 2.20*
R-squared overall	0.009	0.009	0.009	0.030	0.030	0.030	0.041	--	0.033
No. of observ.	298	298	298	298	298	298	298	298	298

SRI is index of risk on site; *ORGDES* is a level of complexity of site organizational design.

* Significance level: $p < 0.1$.

** Significance level: $p < 0.05$.

*** Significance level: $p < 0.01$.

Table 7. Incidence of accidents rate (ACCRATE) and control variables on return of assets (ROA) in the same year.

Variables	Pooled (1)	Random effects (2)	Fixed effects (3)	Pooled (4)	Random effects (5)	Fixed effects (6)	Pooled (7)	Random effects (8)	Fixed effects (9)
ROA_{t-1}	0.351***	0.327***	0.063	0.349***	0.321***	0.059	0.337***	0. 322***	0.018
ACCRATE				4.596**	4.800**	7.972***	2.0317	2.0359	1.994
Chasseturn	0.181***	0.182***	0.170***	0.183***	0.183***	0.166***	0.1837***	0. 183***	0.1594***
Intercept	0.443	0.495	1.440***	-0.307	-.2847301	0.143	2.1597*	2.2312**	4.724***
Year 2005							1.3747**	1.351	0.408
Year 2006							-0.796	-0.796	-1.361
Year 2007							-1.110	-1.142	-2.412*
Year 2008							-6.329***	-6.390***	-8.429***
Year 2009							-5.9419***	-6.091***	-10.014***
Goodness of fit	F(2,1236) =20.29***	Wald chi2(2)= 46.85***	F(2,273)=22.23***	F(3,1235) = 14.41***	Waldchi2(3)=51.93***	F(3,273) =17.87***	F(8,1230)= 8.52***	[b]	F(8,273)=12.21***
R-squared overall	0.093	0.093	0.058	0.096	0.096	0.040	0.119	0.119	0.045
No. of observ.	1239	1239	1239	1239	1239	1239	1239	1239	1044

ROA is the percent of return on assets; *ACCRATE is the rate of workers injured with respect to the total firm workers*; *$ACCRATE^2$* is the quadratic term of *ACCRATE*; *CHASSETURN* is the perceptual change rate in asset turnover in a given period.

* Significance level: $p < 0.1$.

** Significance level: $p < 0.05$.

*** Significance level: $p < 0.01$.

[b] Not reported

Table 8. Incidence of accidents rate (*ACCRATE* and *$ACCRATE^2$*, quadratic) and control variables on return of assets

Variables	Pooled (1)	Random effects (2)	Fixed effects (3)	Pooled (4)	Random effects (5)	Fixed effects (6)
ROA_{t-1}	0.350***	0.321***	0.060	0.339***	0.322***	0.020
ACCRATE	10.698***	11.069***	16.161***	6.099	6.101*	6.158
$ACCRATE^2$	-4.850***	-4.953***	-6.287***	-3.165*	-3.156**	-3.102*
Chasseturn	0.1845***	0.184***	0.165***	0.185***	0.184***	0.159***
Intercept	-0.936	-0.928	-0.715	1.660	1.738	4.207***
Year 2005				1.400	1.375	0.441
Year 2006				-0.780	-0.781	-1.354
Year 2007				-1.073	-1.107	-2.364
Year 2008				-6.220***	-6.2873***	-8.327***
Year 2009				-5.673***	-5.835***	-9.764***
Goodness of fit	F(4,1234)= 10.78***	Wald chi2(4) =52.80***	F(4,273) = 13.84***	F(9,1229) =7.87***	(b)	F(9,273)=11.04***
R-squared overall	0.099	0.099	0.039	0.120	0.120	0.046
No. of observ.	1239	1239	1239	1239	1239	1239

ROA is the percent of return on assets; *ACCRATE is the rate of workers injured with respect to the total firm workers*; *$ACCRATE^2$* is the quadratic term of *ACCRATE*; *CHASSETURN* is the perceptual change rate in asset turnover in a given period.

* Significance level: $p < 0.1$.

** Significance level: $p < 0.05$.

*** Significance level: $p < 0.01$.

[b] Not reported