

# Modeling the performance impacts caused by an earthquake to the construction industry: Case study on the 2010 Chile earthquake

## Modelación de los impactos en el desempeño causados por un terremoto a la industria de la construcción: Caso de estudio relativo al terremoto de 2010 en Chile

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### Abstract

Natural disasters affect the construction industry in many ways other than the direct damages. This paper presents a model that evaluates the performance impacts caused by an earthquake to the construction industry by using the 2010 Chilean earthquake as case study. The main variables affected by a seismic event in construction companies and their relationships were modeled by means of the use of Partial Least Square (PLS). The modeling framework was developed by interviewing CEOs of construction companies located in areas affected by the earthquake. Then, a model of interrelationships, which would explain how variables are affected by an earthquake was developed. The main findings showed that when a severe telluric event occurs, the two most affected factors were Relationship with the Owner/Clients and Image, while the most affected indexes were Owner/Client Satisfaction and Financial Situation. Thus, this research emphasizes the importance of these four variables (factors and indexes), when the construction industry faces a large earthquake.

**Key words:** Modeling, Partial Least Squares (PLS), earthquake, construction industry, Chile.

### Resumen

Los desastres naturales afectan a la industria de la construcción de muchas maneras distintas más allá de los daños directos. Este artículo presenta un modelo que evalúa los impactos en el desempeño, causados por un terremoto a la industria de la construcción, utilizando el terremoto ocurrido en Chile el año 2010 como caso de estudio. Se modelaron las principales variables afectadas por un evento sísmico en las empresas constructoras y sus relaciones, por medio del uso de Mínimos Cuadrados Parciales. El marco bajo el cual se desarrolló la modelización, fue mediante entrevistas a directores generales de empresas constructoras, ubicadas en zonas afectadas por el terremoto. Luego, se desarrolló un modelo de interrelaciones que explicaría cómo las variables se ven afectadas por un terremoto. Los principales hallazgos muestran que cuando se produce un evento telúrico severo, los dos factores más afectados son Relación con el Mandante/Cliente e Imagen, mientras que los índices más afectados fueron Satisfacción del Mandante/Cliente y Situación Financiera. Por lo tanto, esta investigación destaca la importancia de estas cuatro variables (factores e índices), cuando la industria de la construcción se ve enfrentada a un terremoto de gran magnitud.

**Palabras clave:** Modelación, Mínimos Cuadrados Parciales, terremoto, industria de la construcción, Chile.

Throughout history, mankind has suffered the severity of natural disasters, which have caused the destruction of their cities. Due to these natural phenomena, mankind has optimized its living conditions improving its safety according to its surroundings (hurricanes, tornados, volcano eruptions, floods, earthquakes and tsunamis).

In this regard, earthquakes are one of the most common and destructive natural disasters with a wide range of negative impacts over population (Bertero, 2013). In order to minimize human and economic losses, building codes, design/construction guidelines, manuals and earthquake prediction and prevention models have been developed. These publications and models discuss how to prepare and face an event of this nature. For instance, the Federal Emergency Management Agency (FEMA) has developed a series of procedures to face earthquakes (FEMA, 2017). These procedures not only include aspects related to evacuation, but also technical aspects such as seismic rehabilitation of existing buildings (FEMA-547, 2006). Similarly, other studies have covered a range of topics such as mitigation of post-earthquake effects (Chen, Lee, & Shinozuka, 2004); definition and economical measurement of the natural disasters (Rose, 2004); methodologies for the estimation of losses caused by an earthquake at a given location and how to mitigate its effects (D'Ayala, Spence, Oliveira, & Pomonis, 1997; Whitman, Anagnos, Lagorio, & Lawson, 1998); and risk reduction of non-structural damages (Fierro, Perry, & Freeman, 1994).

Similar to other disasters, earthquakes have secondary, long-term social and economic effects in addition to the immediate effects. Houses, schools, hospitals, churches, buildings, cultural patrimony, roads, ports, aeronautic infrastructure, sports buildings, irrigation, energy and telecommunications systems, both from public and private companies, are only a few examples of constructions affected by seismic events (FEMA, 2017), and reconstruction processes may take not only months but years, with the corresponding economic and social impacts.

Additionally, there are legal obligations that enforce construction companies to be responsible for a building quality as well as to respond because of the damages of a building.

Thus, construction companies play a crucial role, not only in their own survival but also in the reestablishment of previous conditions at the affected regions. Those companies have to be prepared to face the adverse effects coming with an earthquake, along with to know the main aspects they have to take care of when facing a seismic event. For instance, one of those aspects to consider is the "image" of construction companies for the owner or client, not only in terms of quality but also in terms of post-earthquake response. If the construction company responds diligently after a seismic event, the owner/client will have a feeling of confidence and satisfaction due to the commitment shown by the construction company.

In this paper, the effects caused by an earthquake to the construction industry are assessed by using data from the 2010 Chile earthquake. To do so, variables that are affected in a construction company after an earthquake were determined in order to quantify their significance. Analyses were supported by a statistical model of interrelationships between competitive factors and indexes of construction companies under the after-effect of an earthquake. The competitive model developed by Orozco et al. (2013) was used as the basis for the modeling framework discussed in this paper.

The main research objective is the development of a model able to represent factors and indexes in construction companies, which can be affected by a large earthquake.

## Literature review

### Factors in construction companies

The factors that affect companies in general are defined as those internal assets and processes within the organization that generate a competitive advantage, which can be tangibles or intangibles (Ambastha & Momaya, 2004). Here lies the impact of an earthquake on the factors of construction companies, conditioning their performance within the construction industry, given the high globalization of markets and the presence of more and more aggressive competitors, as well as more demanding and complex customers (Suárez, 2004).

From the wide list of factors in literature, Orozco et al. (2013) summarizes some of them found within the construction industry, e.g. image, leadership and, market. Other factors correspond to the number and type of competitors, market prices, size and growth, the systematization level of knowledge applied to control and modify the physical and social environment, political issues, environmental regulations (Venegas & Alarcón, 1997), and regulatory

restrictions (El-Diraby, Costa, & Singh, 2006; Flanagan, Jewell, Ericsson, & Henricsson, 2005; Yates, 1994). Furthermore, there are other factors that can be affected by an earthquake, such as: lack of seasonal workers, labor price inflation and difficulty to obtain construction materials (Henderson & Mitchell, 1997; Venegas & Alarcón, 1997).

Thus, based on the work developed by Orozco et al. (2013), and complemented with the present bibliographical exploration, the main factors in the construction industry affected by severe telluric events were selected and shown in Table 1. The suitability of the factors considered is then analyzed through the evaluation of the model presented in this research.

**Table 1.** Factors in construction companies.

Factors	(Ahire, Golhar, & Waller, 1996)	(Ambastha & Momaya, 2004)	(Dikmen & Birgönül, 2003)	(El-Diraby et al., 2006)	(Hatash & Skitmore, 1997)	(Jaafari, 2000)	(Cheah, Kang, & Chew, 2007)	(Mandal, Howell, & Sohal, 1998)	(Shen, Lu, Shen, & Li, 2003)	(Shen, Lu, & Yam, 2006)	(Venegas & Alarcón, 1997)
Corporate Image		•		•	•	•	•		•	•	
Leadership				•		•		•			
Contracts Management		•		•	•		•				
Employees Capabilities	•					•		•			•
Technical and Technological Capabilities		•	•	•			•				
Business Relationships	•	•	•						•	•	

### Indexes in construction companies

An index measures quantitatively and qualitatively specific objectives through time, by determining the impact of an action taken (United Nations, 1999). In addition, indexes measure, among other aspects, quality, performance and client satisfaction (Ambastha & Momaya, 2004; Bassioni, Price, & Hassan, 2005). In construction industry, other important aspect to measure through indexes is competitiveness (Buckley, Pass, & Prescott, 1988; Orozco et al., 2013), which has demanded to incorporate non-traditional management measurements (Kagioglou, Cooper, & Aouad, 2001). As found for factors, there are a number of indexes too, where only those that can be affected by an earthquake have been selected from, which will have to be ratified through the model developed in this research. Such indexes are presented in Table 2.

**Table 2.** Indexes in construction companies.

Indexes	(Bassioni et al., 2005)	(Buckley et al., 1988)	(Kaplan & Norton, 1993)	(Conti, 1997)	(Flanagan et al., 2005)	(Kale & Arditi, 2002)	(Venegas & Alarcón, 1997)	(Phua, 2006)	(Raynsford, 2000)	(KPI Working Group, 2007)
Owner/client Satisfaction	•			•	•		•		•	•
Quality	•	•	•	•					•	
Motivation and Commitment of Workers			•	•						
Financial Situation	•	•	•	•	•	•	•	•	•	•

## Natural disasters and their impact on the construction industry

For centuries, mankind has had to interact with diverse natural disasters. Worldwide, the economic impact of these natural disasters amounts to 150,000 deaths a year, more than 3 million of sufferers and their associated costs are estimated at US\$48,000,000,000 annually (Montenegro & Peña, 2010). To face the impacts of this type of catastrophes, the Federal Emergency Management Agency (FEMA, 2017) was founded in the United States in 1803 and, the US Geological Survey was created in 1879 (USGS, 2011).

On the other hand, the community impacts of natural disasters may include, but not limited to, physical, psychosocial, sociodemographic, socioeconomic and, political aspects (Lindell & Prater, 2003).

In terms of the effects of natural disasters on the construction industry, construction cost increment is the most relevant impact (De Silva, 2011). Other effects have also been documented, such as the impacts on construction strategies (Li, Wang, Wang, Dong, & Wu, 2011), the enhancement of building codes, standards, materials and construction technologies (Chang, Wilkinson, Seville, & Potangaroa, 2010), and the importance of quality infrastructure in reducing the impacts of disaster risks (Palliyaguru & Amaratunga, 2008). Additionally, Ofori (2002) highlights the importance of giving to construction companies the capacity and capability of planning, designing and building constructed items to reduce their vulnerability to disasters, along with emphasizing the vital role of professionals in the rectification of physical damages of disasters. All of these effects are closely related to the factors and indexes currently present in the construction industry.

The diverse aspects mentioned here will be considered when modeling the effects caused by a natural disaster, e.g. a severe earthquake, to the construction industry, not only to define the latent variables (constructs of the model), but also to elaborate the questionnaire to be applied to CEOs of the construction companies affected by the earthquake under study.

## Methodology

First, in order to define the variables to be considered for the model proposed in this study, a review of literature was conducted. The search focused on the factors and indexes involved in the construction industry described by diverse authors, along with the impacts of natural disasters on construction companies.

Once the variables were defined, a preliminary conceptual model was developed in order to connect the variables found. Since those variables (constructs) need information before running the preliminary model, it was needed to collect such information from interviews to CEOs of the construction companies, located at the zone of the earthquake under study.

Subsequently, this first conceptual model was run several times in order to depurate it, defining the appropriate interrelationships and the final model presented in this paper (this step was conducted based on the statistical analyses required by a technique called Partial Least Square, PLS). After having the final model, the main variables in the construction industry affected by a large earthquake (e.g. the 2010 Chile earthquake), were defined according to the quantitative criteria established by the PLS technique.

### Variables to be used in the model

As mentioned, based on the literature review, factors and indexes observed in the construction industry, which can be affected by a seismic event, are determined by using the 2010 Chile earthquake. These factors and indexes, which are shown below, were incorporated afterwards as variables in the model proposed in this research, to then be validated through the quantitative analysis conducted.

That is how the factors and indexes collected from the bibliographic exploration were complemented through field study obtained from interviews to construction companies that experienced the earthquake of February 27th, 2010, in the south-central area of Chile, hereafter "F/27". Following the variables considered in the proposed model are presented:

*Image of a Construction Company (IMAGE):* Due to F/27 earthquake, public and private sectors were economically affected by countless damages to infrastructures, which caused that construction companies to be questioned by owner/clients. That is why it is intended to measure with this variable; at what extent a severe earthquake affects the image of a construction company.

*Leadership (LEADERSHIP)*: Through this variable, the intent is to measure how a large earthquake affects the leadership of directors or managers of construction companies, in their capacity to have an influence, motivate and support their workers.

*Quality (QUALITY)*: The purpose is to represent if a severe earthquake changes the standards of quality offered by construction companies.

*Contracts Management (CONTR\_M)*: The intent of this variable is to measure how the contract management of projects under development can be affected due to a large earthquake.

*Training (TRAINING)*: The intent of this variable is to evaluate the degree of training of workers to face the consequences of a severe earthquake, in particular during the after-earthquake period.

*Motivation and Commitment (MOT\_COMM)*: This variable measures motivation and commitment shown by the workers, regarding with their corresponding construction companies.

*Technical and Technological Capabilities (TECHN\_K)*: This variable intends to measure how the technical and technological capabilities of construction companies, can be useful to face a large earthquake.

*Financial Situation (FINAN\_S)*: This variable relates to how much the financial situation of a construction company changes when facing a severe earthquake.

*Relationship with the Owner/client (R\_OW/CL)*: The intent of this variable is to measure how much the relationship between the Owner/client of a project affected by an earthquake, and the construction company changes after this type of seismic events.

*Satisfaction of the Owner/client (SATISF)*: This variable intends to represent if there is a change in the degree of satisfaction of the owner/clients of projects after a quake.

*Construction Market (MARKET)*: This variable intends to measure the changes produced in the construction market due to an earthquake, in terms of awarding (or not) new contracts and its effects on construction companies.

Each of these variables correspond to the latent variables of the model, which behavior was measured by means of observable variables collected through the measuring instrument applied in the field study, as explained below.

### **Field study**

The measuring instrument used to collect field information (observable variables), related to the factors and indexes of construction companies affected by an earthquake (latent variables), consisted of personal interviews to CEOs of construction companies, located in the most densely populated cities of south-central area of Chile affected by the 2010 earthquake. The number of companies randomly selected and then surveyed was 15, which represents a 42.9% of the total construction companies directly affected by the earthquake, making up an appropriate sample size for this type of research on construction (Chinowsky, 2001).

In order to ensure the quality and efficiency of the questionnaire, the interview was designed according to the recommendations of Oppenheim (2001). To increase objectivity and reliability of the responses by the surveyed parties, questions related to the names of the interviewees or companies they belonged to, were not included.

As mentioned, the latent variables come from the factors and indexes selected in this study; then, it was needed to determine the observable variables. To do so, for each latent variable a series of questions corresponding to the observable variables was defined, which measured directly the effects of an earthquake on the construction industry. Once the questions were defined, a 7-point measurement scale was prepared, which ranges from "1 = highly negative" to "7 = highly positive". This 7 points scale allows statistical efficiency at the time of evaluating (Buckingham & Saunders, 2004). This type of scale has been widely used in similar researches (Cheah et al., 2007; Luu, Kim, Cao, & Park, 2008).

To improve reliability and validity of the case study in this research, Yin (1994) proposes to conduct four tests to determine the quality of the study: Construct Validity, Internal Validity, External Validity and Reliability.

*Construct validity* establishes the variables that must be analyzed, supporting that the selected criteria reflect what is expected to show. To attain this objective, multiple sources of evidence were analyzed (construction companies affected by the earthquake considered here), and the case study was reviewed by a reliable source (experts in construction, both academics and professionals).

*Internal validity* establishes the causal relationships and if they are supported. To achieve this objective, corresponding literature was reviewed with the purpose of identifying the spurious relationships, which were eliminated afterwards.

*External validity* is used when needing to compare various case studies, establishing the field at which the finding of a pattern case study can be generalized. Since this study corresponds to a particular exploratory non-comparative study, it was not needed to apply this validity criterion.

*Reliability* shows the quality of the information in terms of how was obtained; therefore, if a researcher wants to research again the case study (not a replica), by using the same research method, the same results must be obtained. To ensure *reliability* of the study, this paper represents a protocol to follow that describes all the steps taken during the course of the research and the information collected, which enables to research again the case study and to obtain the same results.

As usual in this type of studies, once the questionnaire was prepared, and prior to its application, a “pilot survey” was conducted. This procedure consisted of applying the questionnaire, to a set of five randomly selected senior managers, of some of the most important Chilean construction companies, affected by the earthquake under study. This enabled to measure the response time, as well as to evaluate if the questions represented properly the observable variables, making possible to evaluate the latent variables afterwards (factors and indexes of a construction company affected by an earthquake), considered in the proposed model.

## Model development

Prior to the presentation of the model, the statistical tool to confirm the results will be explained, in this case, Partial Least Square, and then a conceptual model will be presented upon which the definite model will be built.

### Structural Equations and Partial Least Square

One of the purposes of empirical researches is to confirm causal relationships between various variables under research. Structural equation models are a family of multivariate statistical models that allow estimating the effects and the relationships between constructs and observable variables (Ruiz, Pardo, & San Martín, 2010). In particular, when studying qualitative data, there is a technique called: Structural Equation Modeling (SEM), being Partial Least Square (PLS) a SEM technique (Caballero, 2006).

The SEM method enables to represent reality through complex models, by doing a multiple regression analysis between latent variables (Barroso, Cepeda, & Roldán, 2010). These models are the conjunction of three techniques: 1) generalization of the traditional factorial model to the multivariate case; 2) path analysis and; 3) simultaneous equation models used in economics (Agdas, Washington, Ellis, Agdas, & Dickrell, 2014).

For a proper election between SEM methods: PLS versus Covariance-based method, Chin (1988b) proposes the application of three criteria: 1) If the model constructs are indeterminate (the construct is defined by its indicators plus an error factor), or if the constructs are definite; 2) If the author has a degree of confidence, high on one side, and low on the other, with the theoretical model and in the auxiliary theory that relates to the observable variables, with their corresponding constructs, and 3) If the author is driven towards the estimation of parameters or towards prediction.

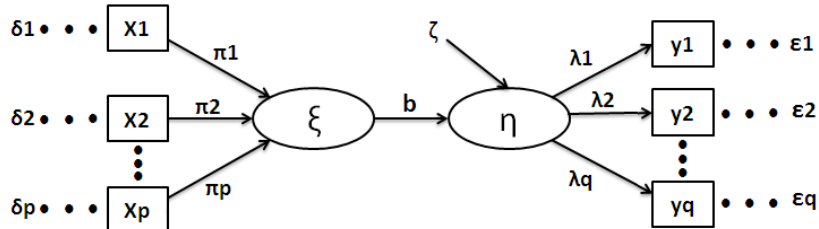
If in each case the first option is chosen, the most convenient method to use is the Covariance-based, otherwise, it is recommended to use the PLS method.

In this research, it has been decided to use the PLS method since one of the issues in using Covariance-based is its difficult determination, i.e. the number of parameters to estimate is too large for the sample size considered; moreover, the constructs are totally defined by their observable variables. Also, the PLS method enables to describe

clearly the causality among variables, and how they come in contact with each other, which corresponds exactly to one of the objectives of this research.

Figure 1 shows a simplified PLS model of two variables or constructs which is built by defining both the structural model (that considers the variables under research) and the relationships between indicators and constructs (Barclay, Higgins, & Thompson, 1995). Figure 1 also defines one direct relationship between two latent variables, indicating the observable variables, correlations and error factors that a structural model can have.

Figure 1. Basic model of two constructs, adapted from (Barclay et al., 1995; Chin, 1988b; Fornell & Bookstein, 1982).



where:

$x_n$ : Variable X, formative, indicator or observable.

$y_n$ : Variable Y, reflexive, indicator or observable.

$\pi_n$ : Weights.

$\lambda_n$ : Loadings.

$b$ : Simple regression coefficient between  $\xi$  and  $\eta$ .

$\xi$ : Exogenous construct.

$\eta$ : Endogenous construct.

$\zeta$ : Residual in the structural model.

$\delta_n$ : Residual from regressions.

$\epsilon_n$ : Error terms.

Considering this simplified example model as a baseline, we proceeded to expand the number of constructs or variables and their corresponding relationships, by using the variables previously presented in this research (factors and indexes affected by an earthquake).

### Conceptual Model and Interrelations between factors and indexes

The conceptual model developed allows identifying relationships between factors and indexes of the construction companies and the construction industry. These relationships pursue the representation of the effects caused by a severe earthquake to construction companies. Figure 2 shows the proposed conceptual model.

Figure 2. Proposed conceptual model that represents the interrelations between factors and indexes of construction companies affected by an earthquake.

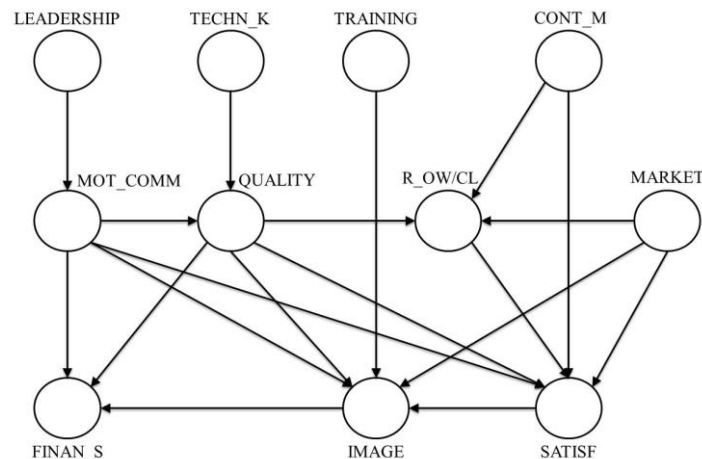




Figure 2 shows those latent variables that are affected by an earthquake the most, determining if correlations proposed are significant. This model was then analyzed and quantified to determine the most important variables (factors and indexes). All the causal relationships between the latent variables (represented by circles) are shown, which are explained by the observable variables (represented by rectangles as will be shown in Figure 3). The model proposed must then be depurated and validated.

### Theoretical bases for validation and reliability of the model

It was necessary to conduct a validity and reliability analysis (Almudena, 2010), so that the observable variables considered in this model represent clearly what is intended to measure from each construct or latent variable. Also, even though measurement and structural parameters are estimated at the same time, a PLS model must be analyzed and interpreted in two stages (Barclay et al., 1995), which are presented below:

- a) Estimation of validity and reliability of the measurement model. The measurement model attempts to analyze if theoretical concepts are correctly measured, through the observable variables. This analysis is completed in relation to attributes validity (it measures what actually wants to measure) and reliability (make it in a stable and consistent way).
- b) Estimation of the structural model. The structural model evaluates the weight and magnitude of relationships between different variables.

### Evaluation of measurement model

Evaluation of the measurement model considers analyzing individual reliability of the item, internal consistency or reliability of the scale, convergent validity and discriminant validity.

*Individual reliability of the item:* estimated by inspecting the loadings  $\lambda$  or single correlations of the measurements between observable variables with their corresponding constructs. To accept an observable variable as part of the construct, the value of the individual reliability of such variable must be greater than 0.7 (Carmines & Zeller, 1979), which implies that shared variance between a construct and observable variables is greater than the error variance. However, some authors suggest that this rule should not be as rigid in the initial stages of a research (Barclay et al., 1995; Chin, 1988b). If observable variables do not comply with this criterion, they can be eliminated in what is called “deputation of items” (Barclay et al., 1995). Other consideration is communality of an observable variable, which part of its variable explained by the construct should be higher than 0.5 (Bollen, 1989).

*Reliability of a construct:* verifies consistency of all the indicators when measuring the concept. It is estimated by inspecting the Cronbach’s Alpha ( $\alpha$ ) applicable in the case of latent variables with reflective indicators. The  $\alpha$  value must be greater than 0.7 (Nunnally & Bernstein, 1994).

*Convergent Validity:* indicates if observable variables of a construct really measure the same concept, making the adjustment of such items significant, which will be highly correlated (Cepeda & Roldán, 2004). Convergent validity is measured through the average variance extracted (AVE) developed by Fornell & Larcker (1981). This variance must be higher than 0.5, establishing that more than 50% of the variation of the construct is due to its indicators.

*Discriminant validity:* indicates at what extent a given construct is different from other constructs of the model. In order to verify the discriminant validity, AVE should be greater than variance shared between a construct and other constructs in the model (the squared correlation between two constructs) (Barroso et al., 2010). Discriminant validity coefficients show that all constructs were more strongly correlated with their own measures, than with any other of the constructs, suggesting good discriminant validity.

Thus, Table 3 shows the criteria evaluated to comply with validity and reliability of the model.

**Table 3.** Criteria to evaluate the measurement model.

	Individual Reliability of the Item	Construct Reliability	Convergent Reliability	Discriminant Reliability
Criteria	> 0.7	$\alpha > 0.7$	AVE > 0.5	$\sqrt{AVE} > CORREL$

Once all the criteria mentioned before have been verified, the estimation of the structural model is conducted.



**Structural model evaluation**

The structural model was evaluated through three criteria (Barclay et al., 1995), which are listed below:  
*Evaluation of the coefficient of variation explained R<sup>2</sup>*: indicates the variance of the endogenous construct that is explained by the variables that predict it. The value of R<sup>2</sup> must be greater or equal to 0.1 (Falk & Miller, 1992), since values inferior to 0.1 indicate a low prediction level of the dependent latent variable.

*Evaluation of Coefficient path, β*: indicates up to what extent predictive variables contribute to variance explained of endogenous variables; it evaluates the significance level of relationships between constructs. In order to be considered significant, the coefficients must attain a value of at least 0.2 and ideally above 0.3 (Chin, 1988a). However, Cohen (1988) establishes that although a value of β ≤ 0.1 shows a low significance level in relationships of constructs, it is considered acceptable, even more for exploratory studies, such as the present research. A value of β < 0 shows that the relationship between constructs is not significant, which does not imply that such relationship must be always eliminated, since excessive eliminations during the depuration process may detriment the value of the other indicators of the model.

*Cross-validated-redundancy-index Q<sup>2</sup> of Stone Geisser evaluation*: This parameter offers a measurement of the goodness with which the values observed are rebuilt by the model and its parameters. A model has predictive capacity when Q<sup>2</sup> > 0 for its dependent variables.

Table 4 shows the criteria considered for the evaluation of the structural model.

**Table 4.** Criteria for the evaluation of the structural model.

	R <sup>2</sup>	β	Q <sup>2</sup>
Criteria	> 0.1	> 0.1	> 0

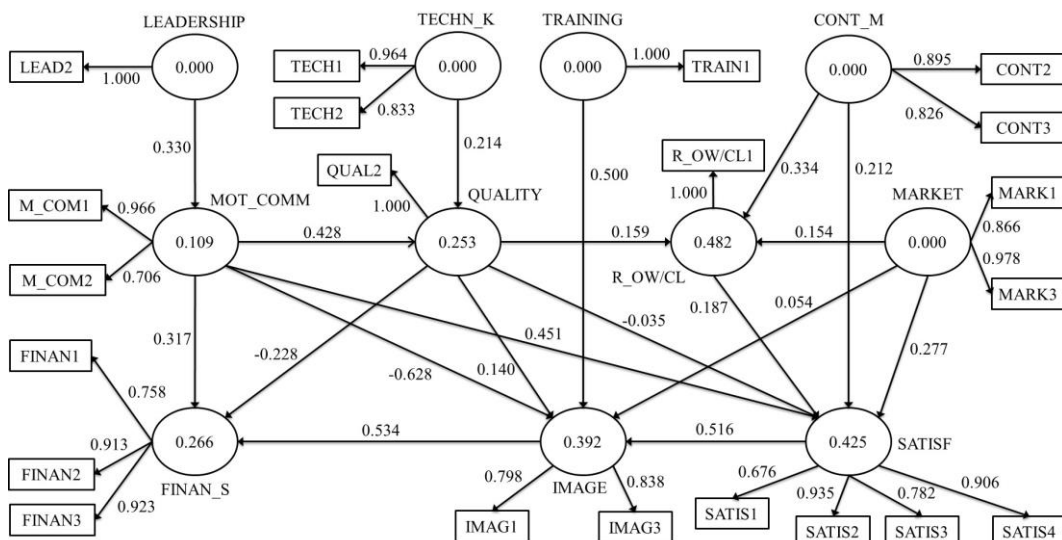
After presenting the validation criteria for the model proposed, next an analysis of results is shown to determine if the model represents properly the effects of an earthquake in the construction industry, based on the case study.

**Analysis of Results**

This section summarizes the results of the evaluation of measurement tests and evaluation of the structural model. As mentioned, the model proposed was evaluated through the PLS method, for which it was needed to use the software SmartPLS (Ringle, Wende, & Will, 2005). This method enables to evaluate relationships between constructs, relationships with their corresponding observable variables; and to estimate evaluation parameters of measurement tests as well as those of the structural model.

After the depuration of some preliminary models, Figure 3 illustrates the final model, in which the new correlations between observable variables and their corresponding constructs are observed.

**Figure 3.** Final model of effects of an earthquake on the construction industry, considering Chile as a case study.



As part of the analysis of the final model presented in Figure 3, Table 5 shows a summary of the main criteria evaluated to validate the model.

**Table 5.** Summary of the main criteria considered for the validation of the model.

Constructs	Reliability of the			R <sup>2</sup>
	Construct	Convergent Validity	Discriminat Validity	
R_Ow/Cl	1.000	1.000	1.000	0.482
Satisf	0.844	0.692	0.832	0.425
Market	0.851	0.853	0.924	
Cont_M	0.657	0.742	0.862	
Finan_S	0.834	0.754	0.868	0.266
Image	0.694	0.766	0.875	0.392
Leadership	1.000	1.000	1.000	
Mot_Comm	0.667	0.716	0.846	0.109
Quality	1.000	1.000	1.000	0.253
Techn_K	0.792	0.811	0.901	
Training	1.000	1.000	1.000	

First, individual reliability values of all the loadings or single correlations, between the observable variables with their constructs, are greater than 0.7 except for SATIS1 with a loading value of 0.678; however, because that loading is close enough to 0.7, it is accepted as valid. Also, the reliability results of the construct provide a Cronbach's  $\alpha$  value greater than 0.7 in four of the seven dependent constructs (Owner/client Satisfaction; Construction Market; Financial Situation and; Technical and Technological Capabilities). The result of the other three constructs (Contracts Management; Image and; Motivation and Commitment), are 0.657, 0.694 and 0.667 respectively. They are considered acceptable for exploratory researches such as this one (Huh, DeLorme, & Reid, 2006). In Convergent Validity tests, the AVE parameter was higher than 0.5 in all the variables and, in terms of Discriminant Validity test, all value of the square root of AVE parameter of variables was higher than the correlation coefficients. Therefore, all the Evaluation of Validity and Reliability of the Measurement Model criteria have been met.

Second, estimation of the structural model started with analyzing the variation coefficient, where all the values of R<sup>2</sup> were greater than 0.1 (values shown within the circles in the model), which indicates that the variables studied have a high predictive power. In terms of the parameter  $\beta$ , most of the values were higher than the threshold value of 0.1, which indicates that the relation between variables was significant. Lastly, when evaluating the Cross-validated-redundancy-index Q<sup>2</sup> of Stone Geisser, all the values were greater than zero, thus it is accepted that the model has predictive capacity for its dependent variables.

Hence, the model proposed meets the validation criteria considered, in which values obtained allow identifying the most relevant factors and indexes affected by a severe earthquake in the construction industry. The discussion and conclusions are presented below.

## Discussion and Conclusions

This study comes from the need to research the consequences produced by an earthquake in the construction industry, taking as case study one of the ten greatest telluric events recorded on human history; the earthquake of February 27th, 2010, in the south-central area of Chile. Given the high degree of damages caused on construction works, construction companies in charge of these works faced the effects of this type of natural events directly.

Therefore, the main objective of this research was to develop a model of the variables that were affected, within the construction companies located in the area of the earthquake under study.

The model proposed illustrates the most influential variables affected by an earthquake; being the identification of those variables important for the construction industry, since this allows focusing on them with the purpose of better facing large earthquakes in the future. Such analysis was also complemented by the responses to open questions applied during this study.

From the analysis conducted, it was found that all the variables had a great predictive power. Particularly, the best representation of the effects of an earthquake was found for the following variables: Relationship with the owner/client; Owner/client satisfaction; Image and; financial situation, which are discussed below:

*Relationship with the owner/client:* This variable is mainly impacted by Quality of projects, Contract management and Construction Market, and it affects Customer Satisfaction. Hence, when facing an earthquake the quality with which projects are performed must be considered, since a good construction that reduces damages has a positive effect in the relationship with the owner/client. Likewise, the way a construction company manages the contract in relation to the corresponding owner/client, must be carefully reviewed upon facing a catastrophe, since special conditions not indicated in the contract may entail problems and misunderstandings, tending to jeopardize relationships with the owner/client. Also, after a force majeure event occurs, the Construction Market tends to modify its behavior, for example, increasing the materials and labor costs due to rationing, leading to eventual incompleteness by construction companies. Finally and also indicated by the model, a good Relationship with the owner/client greatly impacts its Satisfaction.

*Owner/client satisfaction:* Just like the variable mentioned before, construction market has a direct effect on the owner/client satisfaction, since construction companies must face the environment changes. As indicated before, a good relationship with the owner/client has a direct influence over its Satisfaction. An interesting variable to analyze was Motivation and Commitment, due to the model enabled to confirm the experiences collected in the field, showing that those construction companies that took care of the welfare of their employees during and after the earthquake under research (support in the reconstruction of their homes, food supply, etc.), caused an important increment in the Motivation and Commitment of their labor force, which contributed remarkably to the Owner/client satisfaction, who received a timely and professional response from construction companies through their workers. The model also showed that the variable Quality did not have a mayor influence over the Owner/client satisfaction, since this relation is explained indirectly through the appropriate Relation with the owner/client. At the same time, a satisfied owner/client affects directly the Image of a construction company, as shown by the model.

*Image of the construction company:* The variable Motivation and Commitment did not allow explaining directly its influence over the Image of the construction company; however, it indirectly does through the variables Quality, Relation with the owner/client and Owner/client satisfaction. Also, the variables Quality and Construction market had a relatively low value of significance, at the time of affecting the variable Image of a construction company, but both variables explain Image indirectly through Owner/client satisfaction. As expected, the model shows that the first influence over the Image of the construction company is Owner/client Satisfaction, since a satisfied customer is a customer that helps a construction company to position its “brand”, improving consequently its image. In addition, the Training variable was also significant over Image of a construction company, since trained employees generate trust improving its image.

*Financial situation of the construction company:* The Quality variable does not show a direct influence over the Financial Situation of the construction company, though it does with a low level of significance through the variable Image. The significant variables over the Financial Situation of the company were Motivation and Commitment and Image. Motivation and Commitment explains its influence because of motivated and committed workers do not quit their job at a construction company when facing difficulties (e.g. facing an earthquake), reducing the economic impact of hiring labor specialized in construction, which is commonly scarce during a catastrophe, keeping and even improving the Financial situation of the company. Finally, the variable Image showed an important causal relationship over the Financial situation variable, since a good Image allow companies to be awarded more projects, in particular reconstruction projects after earthquakes.

As final conclusion, it can be noted that even though this work enabled to model 11 constructs (between indexes and factors), which have an effect over construction industries when a severe earthquake occurs, the two most relevant factors were Relation with the owner/clients and Image, while the most important indexes were Owner/client satisfaction and Financial situation. Therefore, this research enables to emphasize these four constructs, as the most relevant when a construction company faces a large earthquake.

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