TECHNOLOGY FORESIGHT AT A UNIVERSITY RESEARCH CENTER IN MEXICO: DESIGN AND FIRST RESULTS

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ABSTRACT

Technology and corporate foresight has gained recognition as an instrument to aid the identification, construction and support of technological strategic decisions in organizations. Research and Development Centers (RDC) -a part of the National System of Science Technology and Innovation (SNCTI) in Mexico- could benefit from the results of a foresight process. One of the aims of technology foresight is to “identify areas of strategic research” (Martin, 1995). The main purpose of this paper is to present the progress and preliminary results of the application of a technology foresight process in a university research and development center in Mexico. The technology foresight process was designed based on a literature review -foresight, strategic planning and knowledge management- and is being applied in the Engineering Institute of the National Autonomous University of Mexico (IIUNAM), one of the main research centers in the country. A systems thinking approach is being used in order to identify the mayor stakeholders involved in the strategic planning of the IIUNAM. Research topics of interest (TI) for the IIUNAM were identified to guide the foresight process. For each TI selected, specific research topic (ST) were stablished which will be used to guide the scenario analysis in a next stage of the work. The methodology applied and first results of the technology foresight process is shown. The TI analysed is called: Natural Hazards in Civil Engineering and the ST corresponds to Structural Reliability.

Key words: Technology foresight; corporate foresight; strategic planning; university research and development centers; Mexico

INTRODUCTION

Technology foresight has gained ground as a tool for decision making, not only in public policy work but also for organizational decisions. The experiences in Europe, Asia and the United States are known and has started to replicate in the Latin American region. In Mexico, the first experiences in foresight go back to the early 1970s with public policy work. The most solid background of foresight in Mexico is found in the Barros Sierra Foundation. In recent years, foresight studies have been resumed and it is in this context that this research is carried out (CEPAL, 2013).

Slaughter (1998) stated that universities are or should be “foresight institutions”, given that they are given a priority role as agents of knowledge production. This statement can be said as well for the Research and Development Centers (RDC), even more those RDC that are part of a university. Munck and McConnell (2009) wrote that: “in a knowledge society and in a knowledge-generating institution such as a university, it is natural to participate in a knowledge-based activity such as foresight” (p.34)

The higher education sector has been recognize by the Organization for Economic Cooperation and Development (OECD) and the United Nations Educational, Scientific and Cultural Organization (UNESCO) for the important role that universities and similar institutions have in the execution of research and development (R&D) (OCDE, 2002). According to the Frascati Manual (2002) education institutions include: “all universities, university centers, technology institutes and other postsecondary centers, whatever the origin of their resources and their legal staff. It also includes all research institutes, experimental stations and hospitals directly controlled, administered or associated with higher education centers” (p.71)

Being in the RDC where the researchers are, a process of foresight and the creative exploration of the future, can represent a unique opportunity to relate with researchers of other disciplines having free discussions (Munck & McConnell, 2009) and even more generating networks of contacts and knowledge. This research takes the definition given by B. Martin (1995) of technology foresight: “the process involved in systematically attempting to look into the longer-term future of science, technology, the economy and society with the aim of identifying the areas of strategic research and the emerging generic technologies likely to yield the greatest economic and social benefit” (p.140)

Sacio-Szymanska et al. (2015) stressed out that in the academic literature there is a lack of a foresight model: “dedicated to setting research and development priority research areas and directions by research institutes“ (p.317). This paper contributes to this aim by designing and applying a technology foresight process in a mexican RDC.

The aim of identifying the areas of strategic research is the main focus of the design of a technology foresight process. The design is based on a bibliometric analysis of technology foresight and a later literature review in order to support the design of a systematic process within a RDC that generates knowledge that supports medium and long term planning. Based on this review, a methodology is proposed, from which its application has begun on the topic of interest (TI) to the Engineering Institute of the National Autonomous University of Mexico (IIUNAM). The initial results of the foresight in the TI are also presented.

RESEARCH IN MEXICO

In Mexico, the National System of Science Technology and Innovation (SNCTI) is composed, according to de Special Program of Science and Technology and Innovation (PECiTI) 2014-2018 by the instruments of government, public policy

and planning as well as by the actors from the public, academic and research sectors, and the companies with activity in science, technology and innovation. The National Council of Science and Technology (CONACYT) is the organization that coordinates and functions as an articulating axis of the SNCTI. One of the aforementioned actors are public universities.

Mexico is divided politically into 32 states, it has 95 public states universities with scientific and technological infrastructure. The research system of the National Autonomous University of México (UNAM) is integrated by 71 research centers. One of these research center is the Institute of Engineering (IIUNAM). The IIUNAM, founded 65 years ago, is a community composed of more than 800 people among researchers, academic technicians, students and administrative staff. The IIUNAM in Mexico City has 15 buildings that houses laboratories, offices, common areas and auditoriums. It also has two foreign units in Juriquilla, Querétaro and Sisal, Yucatán; both in Mexico (IIUNAM, 2017).

The IIUNAM initiated a project aimed at identifying the research that it considers strategic for its development or consolidation in the medium and long terms. This project was called Strategic Research Topics (SRT). An important part of this project consisted of the development of a computing tool that allows the generation of bibliometric information to analyze the development of the knowledge disseminated on specific technological topics.

In order to take advantage of the information generated by the SRT project, it was proposed to carry out a foresight exercise as a next stage of the initial project in order to visualize not only the research topic to develop but also the resources that the IIUNAM will need in the future. In an organization, and undoubtedly in a RDC, technology foresight facilitates the formulation of strategies and the identification of priority areas (Öner & Göl, 2007) (Laliene & Liepe, 2015).

In Mexico, although foresight is not a common practice, the realization of this type of exercises is considered in the Organic Law of CONACYT. In its second article, it is stated that the council has 30 attributions, of which number 26 establishes that CONACYT is responsible for: “investigate directly exclusively on the development and state of science and technology for which it must: […] B. perform foresight studies to identify national needs in science and technology, study the problems that affect it and its relations with the general activity of the country” (DOF, 2002, p.2)

Despite the fact that the law stipulates the execution of foresight exercises, in practice there are still few efforts and this work seeks to contribute to the practice of foresight in RDC in Mexico.

THE TECHNOLOGY FORESIGHT PROCESS

The technology foresight process proposed for the IIUNAM is based on a review of the academic literature on technology foresight, corporate foresight and knowledge management. The design proposed is strongly based on bibliometric

analysis (Figure 1). Bibliometric analysis is a method based on the quantitative and statistical analysis of the publications in a specific field of knowledge (Popper, 2008). Listone (2011) identifies the bibliometric analysis as a useful tool that emerged in the fourth wave of foresight and with which one can perform a scan of the environment to identify emerging needs.

The general process for foresight is taken, with is three main phases: the pre-foresight, the foresight and the post-foresight phase. The pre-foresight phase is a preparation stage of the exercise which is carried out in the next phase: the foresight phase. In the post-foresight phase, the activities aimed at materializing the results obtained in the previous phase are carried out. The activities proposed in each phase are detailed below (Andersen & Rasmussen, 2014)

The Pre-foresight phase

This phase is considered very important for an adequate preparation of the foresight exercise to ensure the best possible results. In this phase the following activities are contemplated:

Agreement with the management of the RDC

The main promoter of the process must be the head of the center. Likewise, it is necessary to define a Responsible Group (RG) who will coordinate the entire process. An agreement with the CEO if the RDC is the starting point of the foresight exercise and of the preparation stage.

The main result of this stage must be a clear vision of the objectives to be accomplished as well as the requirements that must be assigned. Also it must be visualized the results and products expected at the end of the foresight process. Str
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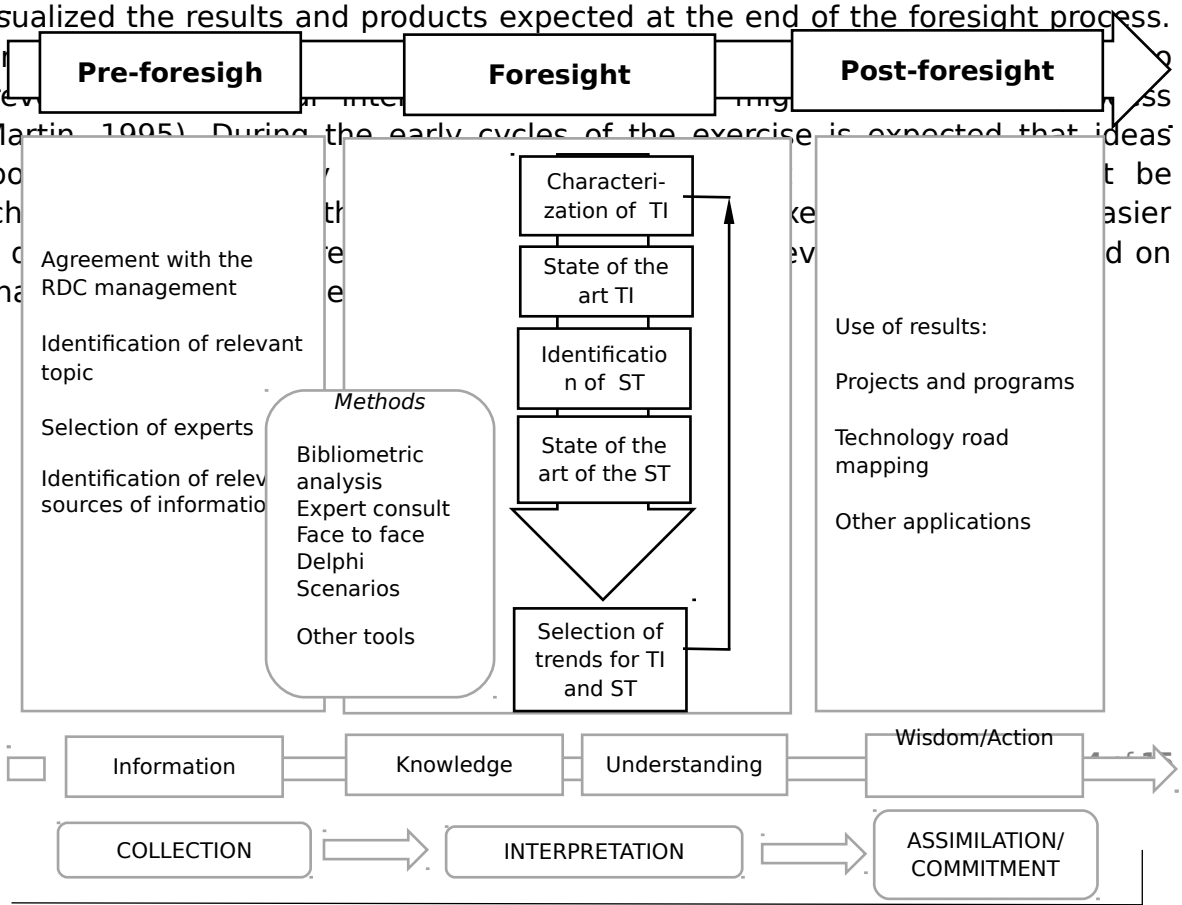

Figure 1. Technology foresight method propose, Adapted from: (Andersen & Rasmussen, 2014) (Labedzka, 2011) (Öner & Göl, 2007)

Identification of the relevant topic

For the technology foresight exercise at the IIUNAM, one of the important subjects to be agreed with the RDC CEO refers to the relevant topics that will be analysed in the exercise. The first cycle of the process exercise is done considering only one topic on interest (TI) for the RDC. This TI is the one in which the RDC has strong competences. Specific research topics (ST) in which the center has interest to consolidate or develop in the medium or long term are identified. ST will help to conduct a more specific exercise, which might facilitate the incorporation of the results into de strategic decisions of the RDC.

Selection of participants

Based on the research topic to be analysed, the RG will propose to the CEO a list of experts who will participate in the exercise. An induction meeting will be convened and held with the experts selected. In this meeting the foresight process will be explained to the participants, as well as the requirements needed from them. It will be stress out that their participation in important for the success of the process.

One of the results from the first meeting is a list of the main sources of information (journals and congresses) in which the knowledge related to the subject is disseminated. An initial group of 8 to 15 experts in considered convenient to be part of this first meeting.

Preparation of the foresight exercise

In this stage, a bibliometric analysis of the subject based on the relevant sources of information suggested by the participants is developed. The list of relevant sources of information provided by the participants in the previous activity is refined using a Delphi query. The RG generates a consolidated list and sends it to the participants, requesting two actions:

Value chain

- To qualify the relevance of the journal/congress to the subject
- To incorporate any other relevant sources of information that are not listed and is consider relevant by them, establishing the relevance of the new source

The answers of the participants will be processed again by the RG and sent back to the experts requesting the review of their previous evaluation based on the averages obtained by each of the sources. The results of this new iteration will generate the list of the sources of information with which the first bibliometric study will be carried out. Based on this bibliometric study, a report is generated and sent to the experts in order to establish a homogeneous knowledge base among them to start the foresight exercise.

Foresight phase

This is the main phase of the foresight process in which the knowledge regarding trends in the TI and in the ST is generated. This phase is based on various meetings with the group of experts. In the next paragraphs the main activities of this stage are developed.

First meeting of analysis

This stage consists of a panel with the group of experts. The panels objective is to gather information and generate new ideas around the ST being analysed (Popper, 2008).

A few days after sending the first bibliometric analysis, time in which the experts can review it, a meeting with them will be called with the following agenda:

- Presentation of the bibliometric report as well as the computing tool used by the RG to analysed the information. In this point an explanation of the way the bibliometric report was made is offered, as well as the results.
- Comments of the participants to the bibliometric report.
- Discussion of the proposal of structure of the topic based on the areas of knowledge involved. The structure of the topic is a relevant aspect given that based on it the ST of interest to the organization will be identifies later. In this meeting a first version of the structure of the RT under study will be adjusted in the next stage of the exercise.
- Agreements of the meeting. The meeting will conclude with the agreements on the bibliometric analysis, any adjustments in the sources of information and the proposed structure of the topic.

Fulfilment with agreements and validation of the structure of the TI

At this point the RG performs all the agreements established in the previous activities. Based on them, the bibliometric report is adjusted. Adjustments are made to the knowledge structure related to the RT.

Once the agreements are fulfil, the RG sends a new bibliometric report and the adjustments to the structure of the theme to the group of experts. It is asks to each of the participants to indicate in which parts of the structure of the subject they can locate their competences, research interests or research activity. A questionnaire will be sent to the participants with questions that help them identified their area of work in the structure.

The responses of the participating experts will be processed by the RG and forwarded to them for their knowledge and in preparation for the next meeting.

Second analysis meeting

A new analysis meeting is called after a few days of sending the information from the previous stage. The participants are asked to review the adjustments to the structure of the theme submitted previously.

The first item on the agenda for this meeting is to discuss briefly the results of the new bibliometric report. Subsequently, the structure of the technological subject matter of the foresight exercise is presented. The RG presents the areas of interest and research competences indicated by each participant. Based on this information, the discussion is opened to identify the ST.

Fulfilment of the agreements and consultation on ST

In addition to the fulfilments of the agreements on the previous stage, the RG sends a new Delphi type query related to de ST to the participants. The answers are processed by the RG and forwarded in a second round to the participants so that each one knows the reasons for and against pointed out by the others and if they considered it adjust their previous comments.

The responses of the participants are again processed by the RG in order to prepare the next discussion meeting. The RG ask the participants to establish the key words associated with each ST, with the aim of making a specific bibliometric report for each ST.

The results on the Delphi query and the new bibliometric report are send to the participants.

Third analysis meeting

The main purpose of this meeting is to discuss each of the ST identified. ST discussions might be prioritized by the RDC management in order of relevance. The specific bibliometric reports provide the guidelines to start the analysis of the technological trends for each ST. It is sought to establish the most probable technological futures in the medium and long terms for each ST.

A result from this meeting is the development of scenarios (trend and radical change) for each ST in this meeting.

Fulfilment with the agreements and scenario validation

The RG will be in charge of executing the agreements as well as carrying out a Delphi type query aimed at validating the scenarios identified of the previous stage. To this end, the information generated in the third meeting is processed to be sent to all participants requesting their comments and observations on the proposed scenarios.

The RG reviews the scenarios based on the answers obtained and forwards a proposal requesting the participants to indicate the level of relevance of each scenarios as well as the probability of success with respect to the other scenario. The scenarios should be clear and to the extent possible, mutually exclusive (Amer, Daim, & Jetter, 2013).

Finally the RG process the responses and sends a final report of this cycle of the foresight process to all the participants and to the management of the RDC.

Post-foresight phase

This phase corresponds to the practical use of the results of the technology foresight process. The results of the exercises attempt to be useful for the planning and institutional decision making of the RDC. This phase is outside the scope of this work, still it represents a fundamental aspect for the formulation of the design presented.

FIRST RESULTS FOR THE APPLICATION OF THE FORESIGHT PROCESS

In this section the first results that have been achieved in the application of the foresight exercise at the IIUNAM are presented. The pre-foresight phase has been a completed, although we acknowledge that the foresight process is not a linear one. In this section mainly results from the first stages of the foresight phase are shown.

Pre-foresight phase

As noted, the exercise of technology foresight in the case of the IIUNAM arises as a derivation of the project SRT whose objective is to identify the research topics that are relevant to the activity of the organization. The RG for the exercise is the same that guided the work of the SRT project.

To begin with the technology foresight exercise, a topic that were considered as a priority in the SRT project was selected. This topic corresponds to the so-called Natural Risks in Civil Engineering (NRCE). NRCE consists of the analysis of the natural phenomena that generate risks in a large part of the basic infrastructure of a region, as well as the knowledge of how to reduce the possibility of its collapse or affectation. The main hazard to analyse in this exercise is the seismic risk.

The previous experience of the SRT project facilitated the execution of the pre-foresight phase. The agreement with the center management were made as well as the identification of the possible participants in the foresight exercise. Likewise, the induction activity was carried out and the main sources of information related to the ST topic were identified. The 15 researchers consulted

identified the most relevant journals in the NRCE topic. Table 1 shows the journal identified.

Table 1: Relevant sources of information identified for the topic NRCE

No	Publication	No	Publication
1	Geophysical Journal International	16	Soils and Foundations
2	Engineering Structures	17	Earthquake Spectra
3	Natural Hazards	18	Wave Motion
4	Tectonophysics	19	Bulletin of Earthquake Engineering
5	Bulletin of the Seismological Society of America	20	Journal of the International Association for Bridge and Structural Engineering IABSE
6	Reliability Engineering and System Safety	21	Steel and Composite Structures
7	Journal of Structural Engineering	22	Journal of Seismology
8	Natural Hazards and Earth System Sciences	23	Disaster Advances
9	Soil Dynamics Earthquake Engineering	24	Probabilistic Engineering Mechanics
10	Canadian Journal of Civil Engineering	25	Journal of Earthquake Engineering
11	Journal of Engineering Mechanics	26	Disasters
12	Earthquake Engineering and Structural Dynamics	27	Journal of Infrastructure Systems
13	ACI Structural Journal	28	Structural Safety
14	Journal of Bridge Engineering	29	Earthquakes and Structures
15	International Journal of Geographical Information Science		

From these journals a first bibliometric report was sent to the participants as the first activity of the foresight stage. Through the bibliometric report, the institutions with the largest number of documents published in the selected journals were also identified. Table 2 shows the 14 institutions with the largest number of documents published in the selected journals were also identified. In fourteenth place appears the National Autonomous University of Mexico (UNAM) to which the IIUNAM belongs.

Table 2: Institutions with the highest production (2000-2016)

Institution	Country	No doc	Institution	Country	No doc
University of California	USA	902	Center Potsdam of Helmholtz	Germany	398
Geological Survey of USA	USA	555	University of Gyeongju	South Korea	395
Civil and Environmental Engineering Colorado School of Mines	USA	525	University of Kyoto	Japan	390
Chinese Academy of Sciences	China	514	University of Tokyo	Japan	376
University of Tongji	China	480	Institut National de la Recherche Scientifique	France	339
Swiss Federal Institute of Technology Zurich	Switzerland	461	University of Napoli Federico II	Italy	309
Istituto Nazionale di Geofisica e Vulcanologia	Italy	404	National Autonomous University of Mexico	Mexico	286

The bibliometric report was sent to the IIUNAM academics selected to participate in the technology foresight exercise in the NRCE topic.

Foresight phase

Within this stage, the first and second analysis meetings were held. A total of 15 academics working in the IIUNAM have participated in the NRCE topic. An important result obtained in this phase, correspond to the structure of the knowledge related to the development of the research subject. Figure 2 shows the structure mentioned in which three large blocks of knowledge were identified.

In this meetings the competences and research interests of the participating academics in the technology foresight process were also identified based on the structure shown in Figure 1.

In a next meeting the some STs based on the structure shown in Figure 2 were identified. One of the ST identified is the so-called topic: structural reliability. We took the ST structural reliability to continue the technology foresight process application.

The RG used the same list of journals identified as relevant by the participants (Table 1) to identify a list of keywords to prepare a bibliometric research. A total of 103 key words were identified and validated with an expert and then put together as a group to prepare a bibliometric analysis. A three subgroups of

words were identified as part of the large group of key words: reliability, risk and vulnerability; being reliability the group with the highest number of key words.

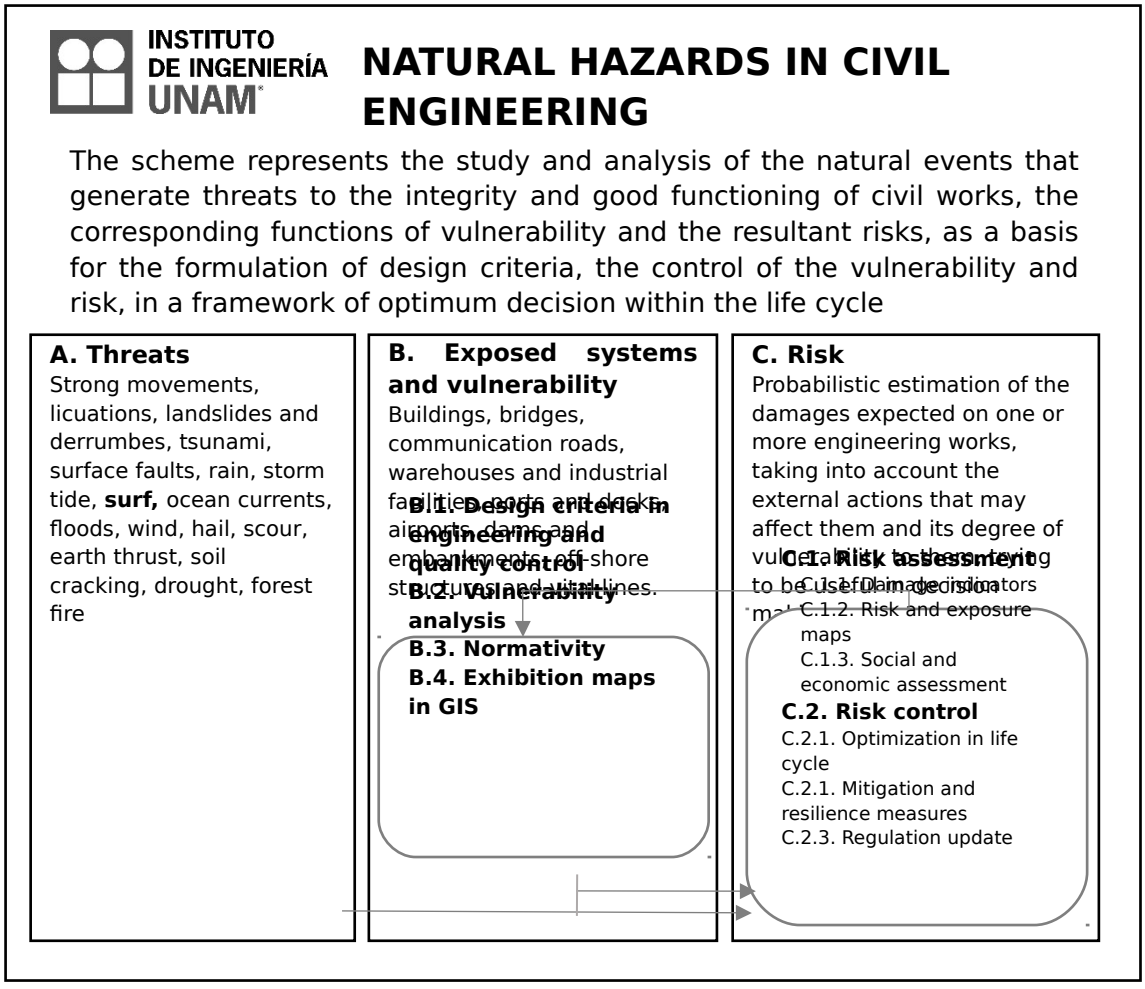

Figure 2: Structure of knowledge related to the NRCE research topic

Of the 29 journals used for the analysis, 10 journals have more than the 80% of the articles for the key word group structural reliability, as shown in table 3.

Table 3: Journals with the highest production for structural reliability (2010-2016)

No	Publication	No doc	Added participation
1	Natural Hazards	412	25.6%
2	Reliability Engineering and System Safety	359	47.9%
3	Structural Safety	148	57.1%

4	Engineering Structures	121	64.6%
5	Bulletin of Earthquake Engineering	61	68.4%
6	Probabilistic Engineering Mechanics	55	71.8%
7	Journal of Structural Engineering	54	75.2%
8	Earthquake Engineering and Structural Dynamics	44	77.9%
9	Disasters	43	80.6%
10	Journal of Infrastructure Systems	42	83.2%

The journal Natural Hazards is where the greatest amount of knowledge on the topic of structural reliability was published in the period 2010-2016. In the same period the topic has an annual growth rate of 15.08%.

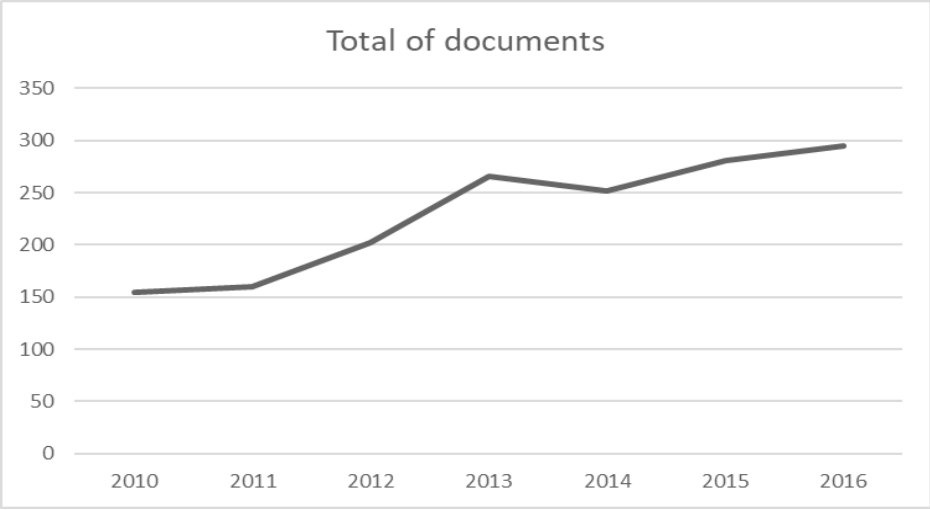

Figure 3: Published documents on structural reliability per year in the period 2010-2016

According to the bibliometric analysis, the countries with the highest production of knowledge regarding structural reliability are the United States of America, China and Italy. Mexico ranks 16th among the countries with the highest production on the ST structural reliability.

Table 4: Institutions with the highest production for structural reliability (2000-2016)

No	**Institution**	**Country**	**No doc**
1	Civil and Environmental Engineering Colorado School of Mines	USA	28
2	Chinese Academy of Sciences	China	15
3	University of Napoli Federico II	Italy	12

4	University of California	USA	11
5	University of Lehigh	USA	11
6	Istituto Nazionale di Geofisica e Vulcanologia	Italy	11
7	University of Tongji	China	10
8	National Autonomous University of Mexico	Mexico	10
9	Indian Institute of Technology Bombay	India	10

The bibliometric analysis on structural reliability, also help us identify the institutions with the largest number of documents published for this ST. The Civil and Environmental Engineering Colorado School of Mines, of the United States of America, is the institution with the highest number of document published for structural reliability. The National Autonomous University of Mexico appears in 8th place.

To date we are working on the preparation of the third analysis meeting aimed at raising the possible scenarios for the ST structural reliability and identifying a second ST.

CONCLUSIONS

Technology foresight studies are increasing in frequency. In particular the studies that has to do with the so-called corporate foresight. In this work we combine corporate and technology foresight approach with the aim of identifying technological trends in the areas of interest of the organizations dedicated to R&D. As we argue earlier, the universities are the main promoters of knowledge as well as the research centers that are part of them.

As a previous step to the proposal to carry out a technology foresight process in a RDC, a bibliometric analysis was carried out. It was observed that a large number of technology foresight exercises reported in the academic literature combine different techniques and are fundamentally based on the experts opinions on the subjects of interests. It was also identifies the increasingly frequent use of bibliometric studies as a primary source of information to undertake consultations with experts. A main characteristic of this technology foresight exercise is the use of bibliometric in order to identify and support specific topics of investigation that are used in the foresight exercise.

Based on the analyses of documents related to the topics of the technology foresight exercise, a methodology is proposed to perform this type of exercises. It is sought that this methodology, when applied in a RDC, becomes a systematic institutional effort whose results support medium and long term planning.

The application of the methodology proposed has begun in the IIUNAM. As part of the pre-foresight phase a research topic was identified: Natural Hazards in Civil Engineering. The foresight phase started with the work to build a scheme of knowledge for Natural Hazards in Civil Engineering. In this scheme three main groups of topics can be observe: threats, exposed systems and vulnerability, and risk. As part of the foresight phase, a specific topic (ST) was identify related to

structure reliability. The results from a bibliometric analysis related with this ST are presented, and it shows a growing interest in the topic.

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