Social sciences and humanities in civil engineering

A mixed methods analysis in the context of education

Doctoral thesis by
Irene Josa

Supervised by
Dr Antonio Aguado
Dr Philipp Rode

Barcelona, September 2021
Department of Civil and Environmental Engineering

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH

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Irene Josa

Doctoral thesis submitted in partial fulfilment of the requirements for the award of
Doctor of Philosophy in Construction Engineering
at the Department of Civil and Enviromental Engineering
of the Technical University of Catalonia.

Thesis supervision:	Antonio Aguado,	Technical University of Catalonia
	Philipp Rode,	London School of Economics
Thesis committee:	Antonio D. de Figueiredo,	University of São Paulo
	Marianna Garfi,	Technical University of Catalonia
	Ana Blanco,	Loughborough University
Substitutes:	Sergio H. Pialarissi,	Loughborough University
	José A. Ortiz,	Universidad Autónoma de Aguascalientes

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Authorship declaration

I, Irene Josa, hereby declare that I am the sole author of this thesis. To the best of my knowledge this thesis contains no material previously published by any other person except where due acknowledgement has been made.

This thesis contains no material which has been accepted as part of the requirements of any other academic degree or non-degree program, in English or in any other language.

Acknowledgements

The completion of this thesis is, in large part, thanks to the special people who have supported and challenged me along my path as a doctoral candidate. I could not have completed this thesis without the financial support of the Agència de Gestió d'Ajuts Universitaris i de Recerca (AGAUR).

I feel tremendously fortunate for having had Antonio and Philipp as my supervisors. *Primero, debo agradecer de manera especial y sincera a Antonio por aceptar realizar esta tesis doctoral bajo su dirección y embarcarse conmigo en esta aventura, cuya temática al principio parecía un tanto arriesgada. Mis innumerables interacciones con él han mejorado significativamente mi trabajo académico y su influencia en mi pensamiento impregna todos los capítulos de esta tesis. No podría haber intentado este viaje sin su guía. En él he encontrado un apoyo constante y, también, a un amigo.*

I owe my gratitude to Philipp for being willing to take me on as a PhD student mid-way through my time at LSE Cities. His feedback always pushed me to improve and develop my thinking, both within and beyond the scope of this thesis. My discussions with him made me think a lot about what it means to be a good researcher, and this is a knowledge that I will carry with me throughout my career.

Surveys and interviews were a key part of this dissertation, and for their deployment many people supported my efforts and gave their time to share their perspectives with me. For the surveys, I am indebted to Napoleón Anento, Irene Arias, Miquel Estrada, Nieves Lantada, Eva Oller, Mariàngels Puigví and Francesc Robusté from UPC, and to Josep Túnica, Javier Bespín, José Javier Valero and Joaquim Llansó for the support given during the distribution and validation of the surveys. For the interviews, I wish to express my deepest gratitude to the 76 interviewees that took part in them, whose names I do not disclose in this thesis due to confidentiality issues. Every person I spoke to made an invaluable contribution to this study –- one which extends far beyond what can possibly be captured here.

In addition to becoming a better researcher, my PhD journey has given me the great opportunity of teaching various courses. I believe that, in teaching, learning is not unidirectional – from the professor to the students – but bidirectional, and I can say that during the past years I take many learnings from the students I have taught. For this, I am thankful to Anna Garfí and Albert de la Fuente, who played an important role by providing me with the opportunity to obtain experience with them in the classroom. They have certainly inspired me to keep growing both as a researcher and a professor. The courses in which I participated at the Institute of Education Sciences gave me many tools to communicate and structure better my ideas, so I would like to extend my gratitude to the institute, with a special mention to Fermín Sánchez and David López for their inspiring lessons.

I am also grateful for the colleagues who have accompanied me during the last years, David, Arash, Karim, Núria, Tai, Stas, Nikola... and my table mates, Sebastián and Milad, with whom besides from sharing table I also shared several interesting conversations. I believe that the social gatherings in the first months of the PhD were key, so a special recognition goes to Francesco, whose BBQ organisational skills were very much missed when he left. Conversations with members of *dobooku* proved very useful to order some ideas in my mind, with a special mention to Guillem Collell and Rosa Grima. 当然，我不能忘我的中国家庭。十分感谢你们，天天，俊辉，飞。我非常高兴当你们朋友，我也很开心当米格的干妈。我希望我可以继续跟你们做曲奇，吃中饭，去公园。

Besides, among all the colleagues, I would like to express my especial gratitude to Rosa. From our *vermuts* in our balcony in Shanghai to the *cafecitos* in plaça Camins, she has accompanied me for several years now. We did our master thesis together, the doctoral thesis together, and I hope that our paths continue to meet in the future.

I feel extremely lucky for having had the opportunity to do a research stay at LSE Cities, and for that time I would like to pay my special regards to my studio-mate, Alexandra Gomes, for our morning conversations and her positivity. Besides, the friendship with Melisa and Martina at RMI, as well as the sisters' support, was critical to survive those first months of a global pandemic. During those months, the 7pm videocalls with the Culleré's also proved monumental towards the success during that period.

Malgrat que he gaudit de cada instant d'aquesta tesi, també m'ha pres temps per a passar amb persones que aprecio. M'agradaria agrair a l'Ester i l'Ernest que m'hagin recolzat (sobretot virtualment), i espero poder reprendre aviat els orientasts i trobades improvisades. Gràcies també a la Meritxell, amb qui estic molt contenta d'haver compartit els últims 10 (!) anys juntes, estudiant, anant a la muntanya, fent passejades... Espero que segueixi així. Penso que una característica important d'una persona realitzant el doctorat és la curiositat. Curiositat per aprendre, per saber més... és per això que m'agradaria dedicar un agraïment especial al Jordi Miralles, que a l'escola em va despertar l'interès en anar més enllà de les coses.

I did part of the very last stages of the thesis, the proofreading, in Mozambique. I was lucky to have Adriana and Eveline by my side to brighten my days.

I wish to express my deepest gratitude to my Mauritian family, who received me with open arms. Thanks particularly to Anupah, Raj and Mala, for their kindness; and to Ma, for being the pillar of the family and for teaching me to make *gâteau patate*. *Mersi bokou.*

Finally, I am extremely grateful to my family. To Alícia, for ensuring that there was always healthy food (somewhere) at home. To Laia and Arnau for their support, sailing trips, scones and cinnamon rolls. Also, to Emma who isn't born yet but who may read this in some decades. To Aina, who is like a sister to me, and whose caring was invaluable and always came when I most needed it. To my dad, who has given me encouragement and support ever since I started studying and throughout the dissertation. He has been – unofficially – my advisor as well. And, finally, to my mum, my partner in crime, without whose everlasting love, endless encouragement, and abundant patience, I would never have got to where I am today.

I owe special gratitude to Nirvan, who has experienced with me the spectrum of emotions and rhythms that this thesis generated, and whose work ethic, patience, and consistency I strive to imitate. His enduring support, willingness to listen, and heroic ability to rescue me from the windmills of my mind have made this thesis possible.

Abstract

The challenges that the world is currently facing call for solutions that are interdisciplinary in nature. This implies that engineering professionals need to work together with professionals from different disciplines to design projects to address such issues. In this regard, Higher Education plays a major role in training engineering students that are able to understand the socio-technical context in which engineering practice is embedded and design appropriate solutions accordingly. Nonetheless, traditionally, engineering education curricula have mainly focused on the “technical” side of engineering and have left the “social” aside. Hence, understanding the processes of integrating social issues in engineering programs is essential.

The main objective of the present dissertation is to understand better the potential contributions from relevant areas of the social sciences and humanities in civil engineering and propose recommendations accordingly. For this, the thesis follows a mixed-methods approach that involved the collection of both qualitative and quantitative data. On the one hand, the qualitative data involved the analysis of faculty members’ perspectives on the processes of integrating knowledge from the social sciences and humanities into civil engineering programs. This approach uses semi-structured interviewing with professors in civil engineering schools. On the other hand, quantitative data was collected through a survey administered to stakeholders studying or working in the context of civil engineering. Interview and survey data were complemented with literature reviews and the analysis of archival records.

First of all, a conceptual framework for the intersection between civil engineering and the social sciences and humanities was developed. For this, the fields of civil engineering and social sciences were classified into several different subfields, namely six for infrastructures (transport, water, energy, environment, urban planning and buildings) and twelve for social sciences (culture and history, behaviour and mind, communication and interaction, socioeconomics, juridical sciences, life and health, politics, social problems, social groups, ethics and philosophy, arts and education and innovation). Afterwards, the existing literature at the intersection between the various categories was reviewed. The final framework provides a description of different key areas and can be applied to a wide variety of actions ranging from the development of university curricula to the social impact assessment of projects.

Second, the empirical part of this thesis analysed the current status of integration of the social sciences and humanities in civil engineering programmes at different levels, national and international. In both cases, four main elements were examined: ability, preparedness, willingness and propitiousness to change. These aspects were analysed through the various sources of data collected and focusing on aspects such as thinking processes, challenges, and opportunities.

Third, following the results of the previous parts, all the previous findings in specific technical fields were built upon to elaborate on two specific case studies through which social elements can be introduced in class. The first case study proposes a multi-criteria decision-making model to assess the sustainability of structural components. The proposed method was employed to evaluate the sustainability of the most representative alternatives (materials and structural typologies) for girders and trusses for the construction of sport halls roofs in Spain. The second case study assesses the sustainability of structural concrete elements in the context of water and sanitation. In particular, it proposes and applies a model for the case of concrete pipes, and it determines how different typologies of pipes contribute to the overall sustainability of infrastructure systems.

Resum

Els reptes als quals el món s'enfronta actualment requereixen solucions de caràcter interdisciplinari. Això implica que els professionals de l'enginyeria han de treballar juntament amb professionals de diferents disciplines per tal de dissenyar projectes que puguin abordar aquests problemes. En aquest sentit, l'educació superior té un paper important en la formació d'estudiants d'enginyeria capaços d'entendre el context socio-tècnic en què s'inclou la pràctica d'enginyeria i dissenyar les solucions adequades en conseqüència. No obstant això, tradicionalment, els programes d'educació en enginyeria s'han centrat principalment en el vessant *tècnic* de l'enginyeria i han deixat de banda la part *social*. Per tant, és essencial entendre els processos d'integració de problemes socials en programes d'enginyeria.

L'objectiu principal de la present dissertació és entendre millor les contribucions potencials d'àrees rellevants de les ciències socials i humanitats en enginyeria civil i proposar recomanacions en conseqüència. Per a això, la tesi segueix un enfocament de mètodes mixtos que involucra la recopilació de dades tant qualitatives com quantitatives. D'una banda, les dades qualitatives es basen en l'anàlisi de les perspectives de professors sobre els processos d'integració de coneixement de les ciències socials i humanitats als programes d'enginyeria civil. Aquest enfocament utilitza entrevistes semiestructurades amb professors d'escoles d'enginyeria civil. D'altra banda, les dades quantitatives consisteixen en les respostes obtingudes mitjançant una enquesta administrada a grups d'interès que estudien o treballen en el context de l'enginyeria civil. Les dades d'entrevistes i enquestes es complementen amb revisions bibliogràfiques i l'anàlisi de registres d'arxiu.

En primer lloc, es desenvolupa un marc conceptual per a la intersecció entre l'enginyeria civil i les ciències socials i humanitats. Per a això, els camps de l'enginyeria civil i les ciències socials es classifiquen en diversos subcamps diferents, concretament sis per a infraestructures (transport, aigua, energia, medi ambient, urbanisme i edificació) i dotze per a ciències socials (cultura i història, comportament i ment, comunicació i interacció, socioeconomia, ciències jurídiques, vida i salut, política, problemes socials, grups socials, ètica i filosofia, arts i educació i innovació). Posteriorment, es revisa la literatura existent a la intersecció entre les diverses categories. El marc final proporciona una descripció de diferents àrees clau i es pot aplicar a una àmplia varietat d'accions que van des del desenvolupament de plans d'estudis universitaris fins a l'avaluació de l'impacte social dels projectes.

En segon lloc, la part empírica d'aquesta tesi analitza l'estat actual d'integració d'aspectes socials en programes d'enginyeria civil a diferents nivells, nacionals i internacionals. En ambdós casos, s'examinen quatre elements principals: capacitat, preparació, voluntat i conveniència per canviar. Aquests aspectes s'analitzen a través de les diverses fonts de dades recopilades i centrant-se en aspectes com processos de pensament, reptes i oportunitats.

En tercer lloc, seguint els resultats de les parts anteriors, totes les troballes anteriors en camps tècnics específics s'utilitzen per elaborar dos estudis de casos específics a través dels quals es poden introduir elements socials a classe. El primer estudi de cas proposa un model de presa de decisions multicriteri per avaluar la sostenibilitat dels components estructurals. El mètode proposat s'utilitza per a avaluar la sostenibilitat de les alternatives més representatives (materials i tipologies estructurals) per a bigues i encavallades per a la construcció de cobertes de pavellons esportius a Espanya. El segon estudi de cas avalua la sostenibilitat d'elements estructurals de formigó en el context de l'aigua i el sanejament. En particular, proposa i aplica un model per al cas de les canonades de formigó i determina com les diferents tipologies de canonades contribueixen a la sostenibilitat global dels sistemes d'infraestructura.

Resumen

Los retos a los que el mundo se enfrenta actualmente requieren soluciones de carácter interdisciplinario. Esto implica que los profesionales de la ingeniería deben trabajar junto con profesionales de diferentes disciplinas para diseñar proyectos que puedan abordar estos problemas. En este sentido, la educación superior tiene un papel importante en la formación de estudiantes de ingeniería capaces de entender el contexto socio-técnico en el que se incluye la práctica de ingeniería y diseñar las soluciones adecuadas en consecuencia. Sin embargo, tradicionalmente, los programas de educación en ingeniería han centrado principalmente en la vertiente *técnica* de la ingeniería y han dejado de lado la parte *social*. Por lo tanto, es esencial entender los procesos de integración de problemas sociales en programas de ingeniería.

El objetivo principal de la presente disertación es entender mejor las contribuciones potenciales de áreas relevantes de las ciencias sociales y humanidades en ingeniería civil y proponer recomendaciones en consecuencia. Para ello, la tesis sigue un enfoque de métodos mixtos que involucra la recopilación de datos tanto cualitativos como cuantitativos. Por un lado, los datos cualitativos se basan en el análisis de las perspectivas de los profesores sobre los procesos de integración del conocimiento de las ciencias sociales y humanidades a los programas de ingeniería civil. Este enfoque utiliza entrevistas semiestructuradas con profesores de escuelas de ingeniería civil. Por otra parte, los datos cuantitativos consisten en las respuestas obtenidas mediante una encuesta administrada a grupos de interés que estudian o trabajan en el contexto de la ingeniería civil. Los datos de entrevistas y encuestas se complementan con revisiones bibliográficas y el análisis de registros de archivo.

En primer lugar, se desarrolla un marco conceptual para la intersección entre la ingeniería civil y las ciencias sociales y humanidades. Para ello, los campos de la ingeniería civil y las ciencias sociales se clasifican en varios subcampos diferentes, concretamente seis para infraestructuras (transporte, agua, energía, medio ambiente, urbanismo y edificación) y doce para ciencias sociales (cultura y historia, comportamiento y mente, comunicación e interacción, socioeconomía, ciencias jurídicas, vida y salud, política, problemas sociales, grupos sociales, ética y filosofía, artes y educación e innovación). Posteriormente, se revisa la literatura existente en la intersección entre las diversas categorías. El marco final proporciona una descripción de diferentes áreas clave y se puede aplicar a una amplia variedad de acciones que van desde el desarrollo de planes de estudios universitarios hasta la evaluación del impacto social de los proyectos.

En segundo lugar, la parte empírica de esta tesis analiza el estado actual de integración de aspectos sociales en programas de ingeniería civil a diferentes niveles, nacionales e internacionales. En ambos casos, se examinan cuatro elementos principales: capacidad, preparación, voluntad y conveniencia para cambiar. Estos aspectos se analizan a través de las diversas fuentes de datos recopilados y centrándose en aspectos como procesos de pensamiento, retos y oportunidades.

En tercer lugar, siguiendo los resultados de las partes anteriores, todos los hallazgos anteriores en campos técnicos específicos se utilizan para elaborar dos estudios de casos específicos a través de los cuales se pueden introducir elementos sociales en clase. El primer estudio de caso propone un modelo de toma de decisiones multicriterio para evaluar la sostenibilidad de los componentes estructurales. El método propuesto se utiliza para evaluar la sostenibilidad de las alternativas más representativas (materiales y tipologías estructurales) para vigas y cerchas para la construcción de cubiertas de pabellones deportivos en España. El segundo estudio de caso evalúa la sostenibilidad de elementos estructurales de hormigón en el contexto del agua y el saneamiento. En particular, propone y aplica un modelo para el caso de las tuberías de hormigón y determina como las diferentes tipologías de tuberías contribuyen a la sostenibilidad global de los sistemas de infraestructura.

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List of abbreviations

Abbreviation	**Meaning**
ABET	Accreditation Board for Engineering and Technology
AGRIC	Agriculture, fishing
ANALY	Data analysis
ANECA	*Agencia Nacional de Evaluación de la Calidad y Acreditación*
ARCHIT	Architecture
ART	Arts and aesthetics
ASCE	American Society of Civil Engineers
ASEE	American Society for Engineering Education
CE	Civil engineering
CHEM	Chemistry, biology
COMM	Communications
CONFL	Conflict resolution
CREAT	Creativity and innovation
CTT	Classical Test Theory
CULT	Culture and history
ECON	Economics, law, politics
EDUC	Education, pedagogy
ESD	Education for Sustainable Development
ETHICS	Ethics and philosophy
EUR-ACE	European Network for Engineering Accreditation
FA	Factor Analysis
FLEX	Flexibility and adaptability
GT	Grounded Theory
HE	Higher Education
HEALTH	Health and quality of life
HIST	History, literature, philosophy
ICC	Information Characteristic Curve
ICE	Institution of Civil Engineers
INFORM	Informatics
INTER	Interpersonal skills
IRT	Item Response Theory
LANG	Languages
LAW	Legislation
MATH	Maths, physics
MCDM	Multiple-criteria decision-making
MEDI	Medicine
MIVES	*Método Integrado de Valor para Evaluaciones Sostenibles*
OCC	Option Characteristic Curve
POLIT	Politics
PROB	Problem solving
PSYCH	Psychology, sociology
SDG	Sustainable Development Goal
SEFI	European Society for Engineering Education
SLCA	Social Life Cycle Analysis
SSH	Social Sciences and Humanities
STEAM	Science, Technology, Engineering, Arts and Mathematics
STEM	Science, Technology, Engineering and Mathematics
TEAM	Teamwork

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1

Introduction

This thesis investigates the potential contribution of integrating relevant content from the social sciences and humanities in civil engineering education programmes. It reviews how the intersection between social sciences and humanities in civil engineering has been dealt with in the literature, and then it examines how the relationship is perceived by various stakeholders focusing on two geographical cases, a national and an international one.

In order to address this research topic, the thesis consists of eight chapters which are described in more detail at the end of this chapter. This first chapter starts by describing the background of the topic under analysis, which serves as a backdrop to understand the research problem tackled. Then, the scope and objectives of the thesis and the publications arising from it are presented.

1.1. Background

The organisation and functioning of many complex societies have grown entirely dependent on many applications of engineering. As such, present societies have been significantly shaped by technology. At the same time, throughout history, the development of technologies has been strongly connected to societal needs, indicating a reciprocal relationship between societies and technology.

Despite this, in the last decades, a divide between the “social” and the “technical” has persisted, both in the engineering profession and education. This has been reflected in changing paradigms of engineering education, as well as in the role that professional engineers have in the context of complex division of labour systems. However, the global issues that are currently being faced demand for practising engineers who can accept and understand the complex nature of the problems and deal with them from an interdisciplinary approach (Lathem et al., 2011). In this regard, engineers, among other scientists, have been regarded as agents of change for progress towards sustainable development (Rodríguez-Solera and Silva-Laya, 2017), together with broader coalitions of political and civil society actors. This role does not necessarily imply that engineers need to possess in-depth knowledge in areas such as the social sciences, but that they need to have certain understanding to improve their ability to work with other disciplines.

To better understand the study area of this thesis, the following subsections describe the historical evolution of the civil engineering profession and education, as well as the need for integrating social aspects in the education of civil engineers. Note that the information presented in these sections does not intend to be exhaustive but to address significant information related to the topic being analysed and provide a basis to improve understanding of the context of the thesis.

1.1.1. Historical context of civil engineering

The focus on civil engineering is due to the fact that the contribution that the social sciences and humanities can make to civil engineering is huge. In fact, the Royal Charter of the first professional institution of civil engineers (the Institution of Civil Engineers, ICE) formally defines the profession of civil engineering as "being the art of directing the great sources of power in Nature for the use and convenience of man (...)". Such a definition illustrates the connections between technology ("the art of directing the power of nature"), environment ("nature") and society ("man"). This emphasises the need to include social aspects in civil engineering education, which has also been formally acknowledged by several civil engineering institutions. For instance, the 2025 vision for civil engineering from the American Society of Civil Engineers (ASCE) revolves around quality of life, ethics, and sustainability and encourages education programmes to incorporate such elements (ASCE, 2007); a recent report by ICE focuses on ways in which infrastructure can create social value and have positive impacts on community life and the well-being of individuals and families (ICE, 2013).

1.1.1.1. Civil engineering profession

Since ancient times, civil engineering has existed, and well-known proofs of this can be found in many parts of the world, from the Chinese Great Wall and the Borobudur temple in Asia, passing by the Roman aqueducts to the Mayan pyramids (Moffett et al., 2003, Straub, 1964). Back then, the profession of civil engineering as it is known today did not exist. The engineers that designed these infrastructures had multidisciplinary backgrounds. Some examples are Imhotep (27th century BCE), considered to be the first documented engineer, who was also an astronomist and a doctor (Jones, 2014); or the Japanese monk Gyōki (668–749 CE), who has been considered to be one of the first civil engineers in Japan (Aoki, 2000).

Formally, engineering professions only emerged during the 19th century (Jørgensen, 2007). Civil engineering was one of the first engineering professions to arise, and it was considered a branch of military engineering focusing on the construction of fortifications and armaments. Despite the knowledge in a wide range of disciplines of engineers in the past, over the centuries, it has been seen that engineers have become increasingly specialised in their disciplines. In fact, an increasing division of labour has been associated with the growing complexity of industrial processes and has been considered key to economic progress by providing cheaper and more efficient means for goods production (Babbage, 1832, Sturn, 2015). These high levels of specialisation have been reflected in various cultures and organisation forms, and a clear depiction of such labour system is the case of the Ford Motor factories in the 1920s, where an assembly line allowed workers to focus on specific jobs, is a clear depiction of such labour system (Janoski and Lepadatu, 2013).

Even though there are similarities regarding the organisation of tasks within societies, differences could also be found in different countries regarding status, professional orientation, placement in industrial hierarchies, or the relative importance given to different engineering competencies. This reflects substantial variations in the division of labour systems regarding the roles of engineers, as well as the historical traditions that have shaped such roles.

Besides the role of job specialisation, it also needs to be noted that until the 1950s, an extended perspective was that reason was the primary source of legitimacy and authority, and the scientific method was given a particularly important emphasis. Such perspective was typical of the Age of Enlightenment movement, which dominated the world of ideas in the 17th and 18th centuries, including ideas on technological progress. In addition, enlightenment thinkers held the notion that rational change could improve humanity. Therefore, before the 1950s, critical reflections on the societal role of science and technology and how its consideration could change the existing labour and science systems were not dominant. Needless to say, there were exceptions. A well-known case is the Spanish multi-faceted engineer Ildefons Cerdà (1815-1876), recognised for his work on urban planning. Other examples of personalities that helped advance these ideas were the engineer and psychologist Lillian Gilbreth (1878-1972) or the road engineer, architect and artist Charles Collier Michell (1793-1851).

1.1.1.2. Civil engineering education

The historical trends described above also manifested themselves in the evolution of engineering education. Three main historical stages have shaped engineering education as it is today. First, the inception of civil engineering education. Secondly, the creation of the traditional engineering disciplines and related subjects resulted from industrial and social development. And, thirdly, the impact that the World War II had on the understanding of engineering and the following rapid increase in the number of engineering disciplines. This is introduced below.

First of all, engineering education was formally incepted towards the end of the 18th century (Rogers, 2002). Before that, knowledge on technology was passed through informal systems, such as directly on the job, from master to apprentice (Reynolds and Seely, 1993). In the last two centuries, the role of educational institutions in defining and instilling the skills and professional identities of engineers has been particularly relevant. As it happened with the engineering profession in different countries, the development of engineering education diverged worldwide, which again reflects the different role that engineering has in society and industry.

Reynolds and Seely (1993) compare the different orientations that engineering education has had through history as a pendulum. As they describe, there have been various waves of practical versus theoretical priorities defining the agenda of engineering education.

Initially, the use of infrastructure and equipment for military purposes inspired the creation of formal training institutions for engineers. The beginning of the formal system of technical education can be located first in France and then in northern Europe. In France, the structure of these institutions developed similarly to that of government institutions and industry (Jørgensen, 2007). They were influenced by the idea of *polytechnique* or the so-called polytechnical competence. The term “polytechnical” has been used to emphasise the broad-based education that has traditionally been given to engineers, which involves an initial introduction to fundamental areas of several fields of engineering (mathematics, natural sciences...) with latter cultivation of a specialisation area.

In northern Europe, there are two models that represent the dominant structures for engineering education. On the one hand, the *fachhochschulen* are based on more practical education, and their name can be translated to Universities of Applied Sciences. In them, education is focused on teaching professional skills, and it is a recruitment path that offers the possibility of becoming practically skilled engineers. On the other hand, the *technische hochschulen* (technical universities) are more similar to university engineering education. This second recruitment path is to be offered to academically trained engineers that come directly from secondary school. The two educational paths emerged from the tradition of separating practically skilled engineers and academically trained engineers. This split between the professional engineer and the practical engineering technician has been seen in other contexts, such as in Wickenden and Hammond (1930).

In the UK, the “learning by doing” style of education was prevailing, and a different institutional model developed. Engineering was perceived as stemming from the practical and skilled crafts, so it was kept apart from the universities and the sciences. Ultimately, the concept of polytechnical education seeped in even though the divide between universities and this practical skills education remained for some time. Another difference was the British system of engineer accreditation, which focused on practical skills and professional experience, whereas in continental Europe, qualifications of engineers were defined through their educational programs. The British system influenced to a great extent the system in the USA.

Today's situation in terms of engineering education has been strongly influenced by the processes resulting from the increase in funding for engineering research during World War II. The construction of a science-based engineering has been considered a significant milestone in engineering education. As Hammond (1944) highlighted, the two world wars had evidenced the need for creating scientific knowledge, innovating and developing technologies, and increasing engineering expertise with the objective of maintaining global leadership and military dominance. In Europe, the post-war trends were towards the formalisation of scientific councils and extensive research programs funded by governments.

An example of how the orientation of engineering research changed was in electrical engineering, where the focus was no longer on electric power and rotating machinery but on electronics, communications theory, or computing machines. With these changes, courses became more abstract and more defined by scientific fields and frontline research than by practical components. A controversy that arose from these changes was the consideration of technical sciences as an applied or as a secondary natural science. At this time, there was an explosion in the number of new engineering disciplines, as well as engineering schools and programmes.

The most recent wave of reforms in engineering was initiated in the 1970s in some engineering schools, and it came after a period of specialised cutting-edge research. These reforms comprised changes both in teaching methods and in contents. On the one hand, in the last decades, several authors had mentioned the existence of an "engineering education paradigm". In particular, according to Smith and Waller (1997), there is an old paradigm of HE teaching that is mainly based on the assumption that students' minds are similar to a blank sheet of paper on which the instructor will write knowledge. In the specific context of engineering education, Felder (2021) mentions that 'a model of teaching as the simple transmission of information from instructors to students has dominated science, technology, engineering, and mathematics (STEM) education for at least a century". Nonetheless, some authors acknowledged a gradual change in paradigm where the divide between the social and the technical started to narrow (Arienti and Marfisi, 1978, Holsapple et al., 2012, Litchfield et al., 2016).

On the other hand, the growth and diversity of technological knowledge have also produced a rapid expansion in the body of knowledge of engineering, as well as an increase in the number of engineering specialities. At the same time, this implied the need for incorporating more courses on technical sciences in technical universities.

Additionally, these new demands on engineering education also included the need for approaching technological problems interdisciplinarily. In spite of this, in many engineering schools, there is still a dominance of disciplinarity rather than interdisciplinarity.

1.1.2. The need for social aspects in engineering

The increased attention to the idea that engineers should be more than just technologists and possess the capabilities to understand and consider public welfare in technology development has been reflected in various publications in the last decades, and an increase in discussions on interdisciplinarity in engineering can be seen in the literature.

Throughout history, there have been several events that have spurred the debate on the responsibility of engineering and have consequently motivated the consideration of social content in contemporary engineering education. One of them is the morality implications behind the engineering of weapons for military use (Forge, 2004, Hashmi and Lee, 2004). More recently, an increase in awareness towards the need for ethical considerations in the use of artificial intelligence (Liao, 2020) or the threats of what is referred to as cyberterrorism (Olmstead and Siraj, 2009) have also increased the debate towards the need for these topics in engineering education.

In 1978, Arienti and Marfisi (1978) discussed whether the engineer's role was to be a "technologist" or an "agent of technological humanism". They analysed the historical conditions that led engineers to "abdicate his social responsibilities" and found that most of the factors were political and socioeconomic. Nonetheless, they argued that a new trend was necessary for engineering, in which engineers would possess a broader perspective of the problems they faced and an understanding of the social context behind numbers.

Apart from the aforementioned study by Arienti and Marfisi (1978), Trevelyan (2014) examined some common misconceptions as to what the engineering practice entails. One of them, he found, was the fact that most factors that define engineering practice are technical. Trevelyan also emphasised that, besides technical factors, social ones also shape how engineering is practised. As they point out,

> [t]o understand engineering, we need to understand human capabilities and social behaviour, as well as the laws of physics. We have to watch what people do, listen to what they say, and understand some of their feelings, both those of frustration and pride (Trevelyan, 2014, p. xxvii).

The civil engineer Frederick Clarke also discussed this perspective of engineering. In his own words, the endeavours of engineers involve:

> the delicate and difficult task of translating scientific abstraction into the practical language of earthly living; and this is perhaps the most completely demanding task in the world. For it requires an understanding of both spheres—the pure ether in which science lives, and also the goals and drives and aspirations of human society in all its complexity. The engineer must be at once philosopher, humanist and hard-headed, hard-handed worker. He must be a philosopher enough to know what to believe, humanist enough to know what to desire, and a workman enough to know what to do (Clarke, F. quoted in Campbell-Allen and Davis, 1979, p. 204).

Among the proponents of the need for making use of the social sciences and humanities in the engineering profession, four main arguments have been made in the literature as represented in Figure 1.1.

The first line of thought is related to the need for engineers to understand where their technologies stand in society from a broader perspective. This includes understanding the impacts of engineering on society or their social responsibility as engineers. These issues were sporadically mentioned in the literature before 1970. However, after the increased acknowledgement of the need for sustainable development, this perspective was increasingly emphasised. In fact, of the 17 goals that make up the Sustainable Development Goals framework (UN General Assembly, 2015), four are directly related to functions developed by civil engineers: SDG 6 (clean water and sanitation), SDG 7 (affordable and clean energy), SDG 9 (industry, innovation and infrastructure), and SDG 11 (sustainable cities and communities).

Second, these engineers would be such whose expertise lies in their capability of aligning their designs with the social context in which the deliverable in question is to be used, in the identification and specification of the needs of people who are supposed to use this product, or in evaluating these artefacts and the related changes. Hence, the second discourse strand looks at the need for engineers to create products that contemplate their traditional engineering characteristics as well as their social

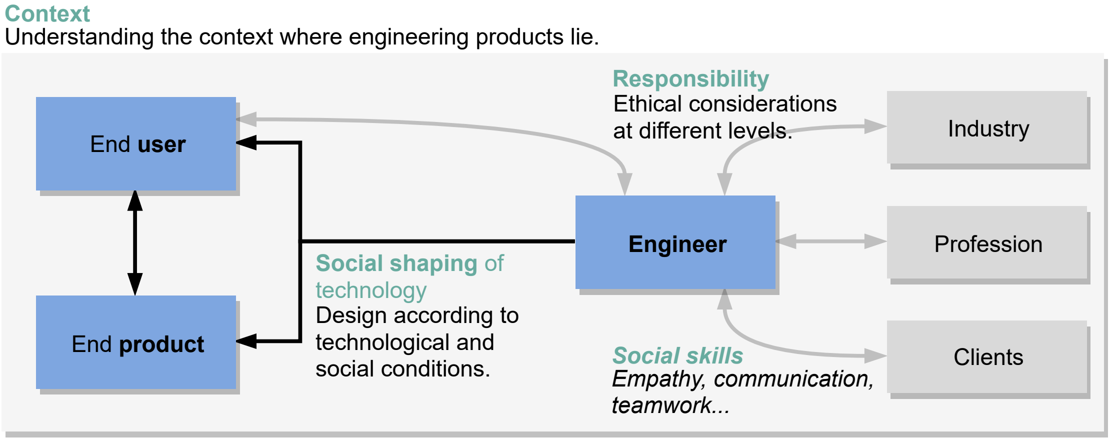

Figure 1.1. Representation of the relationships between the discourses of the proponents of the need for an integration of the social sciences in engineering

features. This involves understanding the human-technology interface and it may require knowledge in disciplines that describe human behaviour such as psychology. In the literature, this is frequently referred to as the human factors in engineering (Lehto and Landry, 2013).

The third rationale is related to the responsibilities of engineers and the accountability of their practices. As Harris Jr et al. (2009) emphasise, responsibility in engineering is not only a matter of using algorithms, but also a question of good judgement. There exist several codes of ethics for the engineering profession, such as the ICE Code of Professional Conduct (ICE, 2017), which contain standards of professional conduct and ethical behaviour.

Finally, there is an additional discourse strand, which is based on the need for engineers to possess more social skills, such as communication, teamwork, organisation, or language skills. In fact, there is a growing body of literature dealing with engineers' social skills, whereby social skills are understood as all those transversal competencies that include aspects such as teamwork, leadership, or communication. Even though this does not involve knowledge in particular fields of the social sciences and humanities, it may allow engineers to work more effectively with social scientists. In fact, the personality of engineers has sometimes been highlighted for its supposed lack of empathy. For instance, Barry (2012) refers to engineers as "technically competent barbarians".

It needs to be mentioned that the different discourses may be complementary, as engineers may want to consider both aspects in their designs. Furthermore, the way in which the inclusion of the social dimensions can be included in the work of engineers can differ depending on the specific task at hand. Different organisation systems and different job positions may demand highly specialised tasks, for which this discussion is of little relevance, and other posts could set responsibilities that require higher levels of interdisciplinarity between engineering and the social sciences and humanities. For instance, social responsibility and the need to understand the ethical implications of technologies (first discourse) have been frequently highlighted in artificial intelligence research, or the need for engineers who understand human-computer interactions has been more palpable in the case of computers engineers.

Figure 1.2 shows different configurations of how civil engineers may benefit from the social sciences and humanities to design their products, ordered from lower to higher level of interdisciplinarity. First, there is the case in which the civil engineers may develop a product or service by themselves; second, they may work together with professionals from the social sciences to develop such element; third, they could use the input from professionals from the social sciences and design the products themselves; and, finally, civil engineers may have an interdisciplinary background and be able to deal with both the engineering and social aspects by themselves. Note that, even though this aspect has not often mentioned in the literature, there may not be an ideal "location" in the continuum represented in the figure. In fact, different engineering works may need different configurations and different levels of interdisciplinarity (for instance, there is a remarkable difference between the design of a concrete pile and the design of an urban plan).

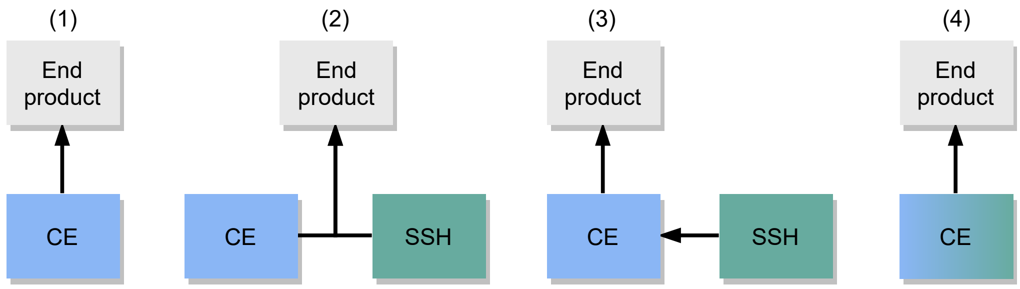

Figure 1.2. Different configurations in which civil engineers and social scientists may work together towards an engineering design

1.2. Motivation

Even though various authors have emphasised the need for integrating content from the social sciences and humanities into engineering, there is still a lack of understanding of what precisely this content should involve and how it could be introduced in practice in the engineering profession. In particular, there are not yet systematic ways in which civil engineering projects can include the various dimensions of the social, nor specific processes in project management where such elements may be included. Besides, it is not yet well understood what areas within the social sciences and humanities may be more necessary in the context of civil engineering; regarding this, literature reviewed above may indicate that the social aspects important for civil engineering could be different for different subdisciplines, such as materials science or urban planning.

In addition to the importance of that gap in the practice dimension, a better understanding on how the social sciences and humanities can be introduced to the education of engineers is also essential. The interest in analysing the social-technical dichotomy particularly in engineering academia stems from the fact that the perception of the divide between the technical and the social dimension is perpetuated throughout engineering education. Engineering education research has shown that the normative definitions of engineering have frequently dismissed the non-technocratic side of engineering. In fact, some argue that there has been a dualisation of knowledge in engineering in which the "technical" is valued over the "social". This dualism is referred to as a socio-technical dualism in Leydens and Schneider (2009).

In light of the above, this dissertation focuses on understanding the contemporary rational, challenges, and opportunities related to the inclusion of social issues in civil engineering. Understanding well how the social factor can be introduced effectively in civil engineering programmes, and what the barriers and catalysers for it are plays a central role in the (social) sustainability of the built environment. As it has been described above, the evolution of the engineering profession has shown shifts between the social and the technical. Apart from in practice, this dualism has also been evident in engineering education.

Additionally, on the one hand, the specific case of civil engineering has been chosen for various reasons. First of all, the impacts that civil engineering projects have on society are enormous. For instance, infrastructure serves as a protection from the inclemency of nature with resilient buildings; it provides a basic service such is water; communication infrastructure such as roads, bridges and ports allows people to other locations. This, at the same time, increases the interactions between human settlements and catalyses commerce and communication. Therefore, understanding social impacts of infrastructure and considering them in professional practice is of utmost importance. Secondly, because a need for a change in civil engineering education has already been advocated by some authors (Sack et al., 1999).

On the other hand, the situation of Spain in terms of perception towards the integration of social aspects is given a special attention in this thesis. In the last decades, the construction sector and the civil engineering profession in Spain have suffered a decrease in positive perception among society. Planas et al. (2016) analysed the possible causes for this decline.

During the years of economic growth in Spain, several high budget public investments were made. The lack of transparency in the definition of the needs for these investments and in the way in which the investment recipients were chosen contributed to the creation of a negative image for the entire construction sector, including the entire public procurement system. A second aspect that Planas et al. (2016) highlight is the high accident rate that characterises the construction sector, as well as the severity of the accidents occurred.

A third element that Planas et al. (2016) emphasise is the fact that there exist several deficiencies associated with poor execution of the works. This is partly due to inadequate training of professionals. In fact, Dainty et al. (2004) pointed out at the the poor image that the the construction industry offers, which leads well-trained professionals to discard dedicating their careers to it.

A fourth element that may influence the negative perception towards the construction sector are the environmental and social impacts that are caused by construction works. Civil engineering project can generate discomfort in nearby communities, such as traffic problems, economic losses or worsening of the air quality. In fact, historically, economic parameters such as cost reduction and profit maximisation have been more important than social costs in in construction projects. This has been perceived by some citizens as if civil engineers do not seek the common good, but their own benefit (Planas et al., 2016).

It is for the various elements that have affected the construction sector in Spain that it is relevant to analyse the case of civil engineering education in this country in more detail.

1.3. Scope and objectives

The primary objective of this dissertation is to fill the gap described above by understanding better the potential contributions from relevant areas of the social sciences and humanities to civil engineering education and proposing recommendations accordingly. For this purpose, the following research questions were formulated:

- **Research question 1** (identification): what areas within the social sciences and humanities are considered as most relevant for civil engineering in the literature and among relevant stakeholders directly related to civil engineering?
- **Research question 2** (assessment): how are the social dimensions of civil engineering perceived in civil engineering academia, and what are the barriers and catalysers for incorporating social aspects in the education of civil engineers?
- **Research question 3** (development): in what ways can social aspects be effectively integrated into the education of civil engineers?

The previous general objective and set of research questions can be translated into three main specific objectives as follows:

- **Specific objective 1**. To compile comprehensive state-of-the-art information concerning the intersection between civil engineering and the social sciences and humanities.
  - Specific objective 1.1. To build a conceptual framework as an approach to better understand the social dimensions in civil engineering.
  - Specific objective 1.2. To examine the status of civil engineering education in a global setting, including how social issues are being integrated and the curricula and the conceptual and legislative aspects framing it.
- **Specific objective 2**. To analyse what the perceptions among civil engineering academia are towards the relationship between the social sciences and humanities and civil engineering.
  - Specific objective 2.1. To analyse the perceptions at different levels, including a national/global scale, from the perspectives of students/professors and between academia and industry.
  - Specific objective 2.2. To compare the perceptions between the groups specified in specific objective 2.1.
- **Specific objective 3**. To propose specific ways in which social dimensions can be more effectively integrated into different subjects of civil engineering programmes.

1.4. Research dissemination

The publications and talks arising from this thesis are included next. When the contents from a chapter have been based on one or more of the articles, this is indicated so in the beginning of such chapter.

Papers published in indexed journals:

[1] Josa, I. & Aguado, A (2019). Infrastructures and society: from a literature review to a conceptual framework. *Journal of Cleaner Production*, 238. DOI: 10.1016/j.jclepro.2019.117741

[2] Josa, I., Pons, O., de la Fuente, A. & Aguado, A. (2020). Multi-criteria decision-making model to assess the sustainability of girders and trusses: Case study for roofs of sports halls. *Journal of Cleaner Production*, 249. DOI: 10.1016/j.jclepro.2019.119312.

[3] Josa, I. & Aguado, A (2020). Measuring Unidimensional Inequality: Practical Framework for the Choice of an Appropriate Measure. *Social Indicators Research*. DOI: 10.1007/s11205-020-02268-0

[4] Josa, I., de la Fuente, A., Casanovas-Rubio, M. M., Armengou, J. & Aguado, A. (2021). Sustainability-Oriented Model to Decide on Concrete Pipeline Reinforcement. *Sustainability*, 13. DOI: 10.3390/su13063026

[5] Josa, I. & Aguado, A. (2021). Social sciences and humanities in the education of civil engineers: current status and proposal of guidelines. *Journal of Cleaner Production*, 311. DOI: 10.1016/j.jclepro.2021.127489

[6] Josa, I, & Aguado, A. (*currently under review*). Analysis of perceptions towards social competencies in engineering academia and industry.

[7] Josa, I, Cartelle-Barros, J.J., Cruz-López, M.P., del Caño Gochi, A., Josa, A. & Aguado, A. (*currently under review*). Integrated corporate framework for the management of the sustainability objective in projects.

The work presented in Chapter 5 is in preparation to submit as a journal article.

Papers presented at conferences:

[1] Josa, I. & Aguado, A. (2019). Infrastructure, innovation and industry as solutions for breaking inequality vicious cycles. *IOP Conference Series Earth and Environmental Science*, 297(1). DOI: 10.1088/1755-1315/297/1/012016

[2] Josa, I., Pons, O., de la Fuente, A. & Aguado, A. (2020). Evaluación de sostenibilidad de

diferentes materiales para elementos estructurales de cubiertas. *Hormigón y Acero*. DOI: 10.33586/hya.2020.2402

Presentations at international conferences:

[1] Josa, I. & Aguado, A (2018). Using MIVES multi-criteria approach for evaluating multidimensional poverty and inequality. *2018 Salzburg Conference in Interdisciplinary Poverty Research*.
[2] Josa, I. & Aguado, A (2019). Multi-criteria tools for the delivery of socially sustainable infrastructure. *UCLG Congress - World Summit of Local and Regional Leaders*.

1.5. Thesis organisation

The present thesis is organised into three main parts in addition to the introduction and conclusion. These parts are directly related to the objectives. The first part sets the theoretical framework of the study. The second part, empirical analysis, uses a mixed-methods approach to analyse the state of civil engineering education at different levels and from different perspectives. Finally, the third part uses the conclusions from the previous chapters to develop two case studies. Eventually, the document is organised in eight chapters as described below and shown in Figure 1.3.

The present chapter, ***Chapter 1 – Introduction***, has set the motivation for the research and defined the scope and structure of the dissertation. There is some terminology that is used in the dissertation that needs to be defined beforehand. This is why ***Chapter 2 – Methods*** starts by defining some preliminary concepts that are key to understand the following chapters. Then, the methodological framework used in the different studies of the thesis is presented, including both quantitative and qualitative analysis methods.

Chapter 3 – Theoretical framework addresses the gap existing in the state-of-art understanding of infrastructures and of social sciences from a socio-technical point of view. Based on the UNESCO nomenclature, the fields of civil engineering and social sciences are classified into several different subfields, namely six for infrastructures (transport, water, energy, environment, urban planning and buildings) and twelve for social sciences (culture and history, behaviour and mind, communication and interaction, socioeconomics, juridical sciences, life and health, politics, social problems, social groups, ethics and philosophy, arts and education and innovation). Afterwards, I review the existing literature at the intersection between the various categories. I conclude by proposing a framework that can support decisions and actions made at different levels and working areas. The framework includes an approach through which to think about and integrate different social dimensions in civil engineering. The approach provides a description of different key areas and can be applied to a wide variety of actions ranging from the development of university curricula to the social impact assessment of projects. This potential use of the framework is then tested in the following chapters.

Chapter 4 – Current status worldwide examines what the status is with regard to the introduction of social issues in civil engineering education worldwide. It uses a triangulation method that combines the use of qualitative and quantitative data to analyse the perceptions, the actual status and possible barriers for the incorporation of social aspects in the studies of civil engineering. Besides, it analyses and discusses the different methodologies in which engineering students can be introduced to these topics. For this, accreditation criteria, civil engineering syllabuses of 100 faculties, and the data collected from interviews with 59 professors worldwide are examined parallelly.

Chapter 5 – Current status in Spain analyses the status regarding the integration of relevant content from the social sciences and humanities in civil engineering education for the case of Spanish engineering schools. This is studied through the analysis of responses to a questionnaire answered by civil engineering professors and through a qualitative approach that explores faculty members' per-

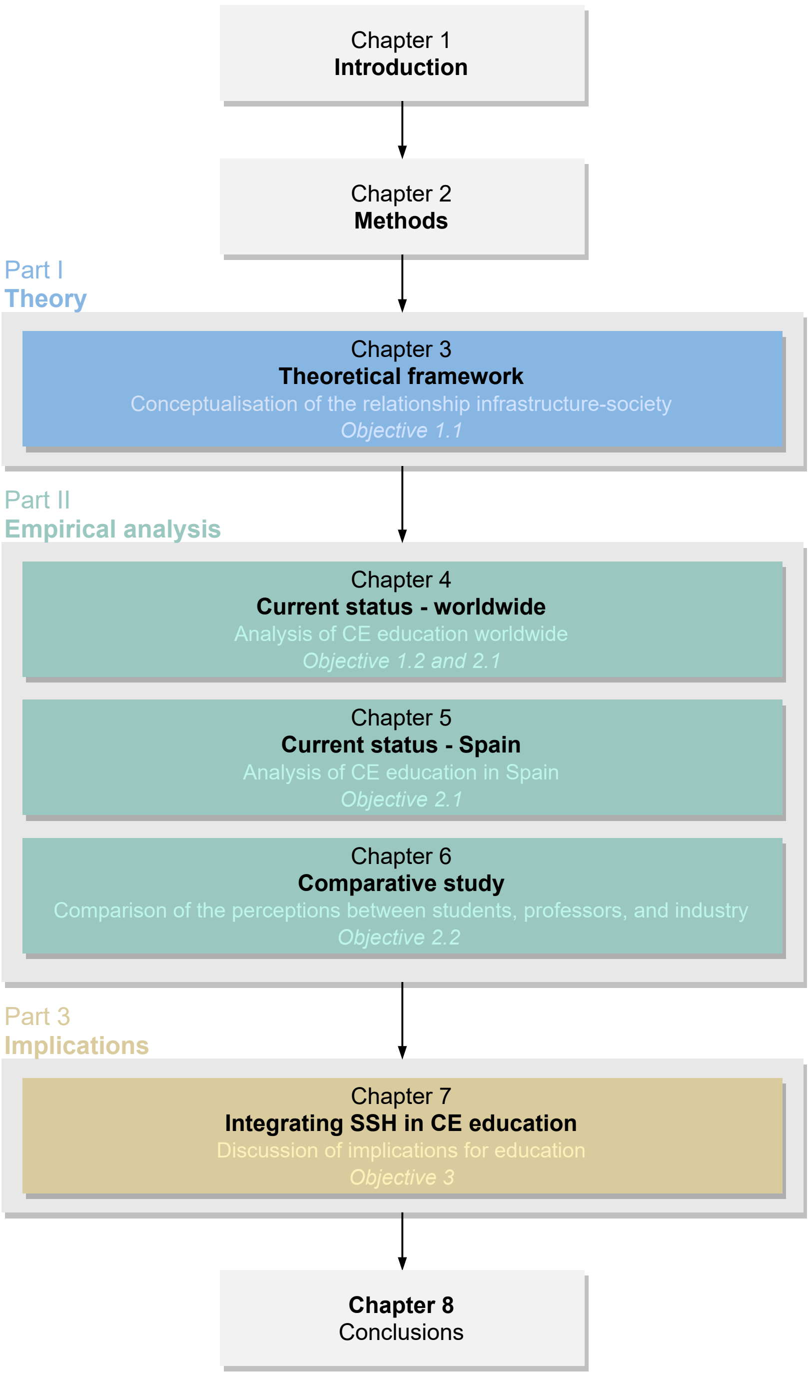

Figure 1.3. Structure of the thesis

spectives on the processes of integrating knowledge from the social sciences and humanities into civil engineering programs. This qualitative approach uses semi-structured interviewing to guide the collection and analysis of interview data in order to identify emerging categories and generate the theory. For this particular study, the data comprised interviews with 24 professors from three different Spanish civil engineering schools.

Having analysed the status of the civil engineering education mostly based on the perspectives of faculty members, ***Chapter 6 – Comparative study*** compares the perceptions between different groups within civil engineering academia and industry regarding three main areas. The first area analysed is the conceptualisation of what the social within civil engineering is; the second one is the perceptions towards the inclusion of social aspects in civil engineering education; and the third aspect analysed is the social skills necessary for civil engineering professionals.

Chapter 7 – Practical implications draws from the gaps detected in the preceding chapters to propose two specific activities that may serve professors as tools to introduce relevant content from the social sciences and humanities into their subjects. In particular, two different models for the sustainability analysis of infrastructure elements are developed. This is done through the Integrated Value Model for the Evaluation of Sustainability method, known by its Spanish acronym, MIVES (*Modelo Integrado de Valor para una Evaluación Sostenible*). This method draws on multi-attribute utility theory and allows building an integrated value model to approach multi-criteria decision-making. The first application is oriented explicitly to beams and girders, and it is applied to assess the sustainability of different alternatives of beams and trusts to support the non-accessible roof of a sports hall in Vila-seca, Spain. The second application is focused on piping systems, which are essential components in the water supply chain and in waste disposal systems worldwide. This application focuses on the sustainability analysis of reinforced concrete pipes. The model is calibrated by assessing various concrete reinforcement strategies (steel bars or steel/synthetic fibres).

Finally, ***Chapter 8 – Conclusions*** presents the main conclusions derived from the results of the doctoral dissertation, and suggests future research directions.

2

Methods

2.1. Methodology overview

The present chapter describes the series of procedures and considerations taken to answer the research questions of the thesis. It starts by giving an overall perspective of the methodology used. In particular, secondary analyses of archival records and a mixed-methods approach involving a primary survey and expert interviews were carried out. Then, the following sections introduce the three main data collection methods and respective analysis procedures used in the dissertation: methodology for secondary documents analysis, for the survey, and for the interviews.

2.1.1. Mixed-methods approach

As discussed in the previous chapter, this dissertation aims to investigate the potential contributions from relevant areas of the social sciences and humanities in civil engineering, mainly focusing on its conceptualisation and the different factors influencing its integration in educational programmes.

To address the objectives of the thesis, the research design was based on a mixed-methods approach which included the analysis of secondary documents, the use of quantitative data obtained from a survey, and of qualitative data collected through interviews.

There exist variations in the precise definition and use of mixed-methods. In this dissertation, the mixed-methods approach consisted of a combination of both quantitative and qualitative methods for data collection and analysis. Creswell (2012) recommends conducting a mixed-methods study when the analysis of both types of data together can help to better understand the phenomenon under investigation. In mixing methods, a fuller picture of the various issues affecting the phenomenon analysed. As Kratochwill and Stoiber (2000) noted, "interweaving of quantitative and qualitative research methodologies so that the most accurate and authentic picture of the knowledge bases and skills associated with change processes is available" (p. 600).

As Creswell (2012) described, quantitative data are useful to obtain characteristic data from a large number of people, whereas qualitative data have the advantage of offering multiple perspectives on the research topic and providing a fuller picture of the processes taking place. Sometimes, using one single type of data, quantitative or qualitative, is not enough to address the answer the research questions posed. Creswell also mentions that "[o]n a practical level, you use mixed methods research for studies in graduate programs in which qualitative research has yet to be fully accepted and in which quantitative approaches are the norm” (Creswell, 2012, p. 535).

Even though the above was not the main reason why the mixed-methods approach was chosen for this dissertation, the great majority of dissertations in civil engineering schools follow quantitative approaches. While this thesis is situated within a doctoral programme in the context of civil engineering, it borrows heavily from other disciplines, such as educational sciences, which connect with the research questions defined. The combination of both types of data was, hence, suitable in terms of the research objective but also in terms of the context of the university.

Leech and Onwuegbuzie (2007) described various typologies of qualitative, quantitative, and mixed-methods research approaches. Among these typologies, in this thesis, the mixed-method approach is employed across research objectives, type of data, type of analysis, and type of inference. Leech and Onwuegbuzie (2007) refer to this typology of mixed mixed-methods design as the fully mixed methods. Besides from the levels at which the mixed-methods approach is applied, Creswell and Guetterman (2018) identify three main mixed-methods designs, which are the following:

- Convergent design, in which quantitative and qualitative data are collected simultaneously, and the results are analysed and used to understand the problem.
- Explanatory sequential design, in which quantitative and qualitative data are collected sequentially so that the results of one of them informs the other one. The two-phase data collection process starts by obtaining quantitative data, the results of which can help in the selection of participants for the qualitative phase.
- Exploratory sequential design, which is similar to the explanatory design but starts with the collection of qualitative data, and quantitative data is collected in a second phase.

2.1.2. Research design

There exist overlaps between the above design typologies, and more complexity could be added to the approaches by combining methods or introducing more steps. In particular in this thesis, a convergent design as shown in Figure 2.1 was utilised. Quantitative and qualitative data were collected separately, and then results were used to obtain the picture of the problem. Nonetheless, it needs to be noted that, because of practical reasons, data were collected sequentially.

It needs to be noted that the research sites from which participants were selected differed slightly for the quantitative and qualitative data. The surveys were distributed among students, professors and practitioners in a specific region of Spain (Barcelona), while interviews were carried out to professors from Spanish universities as well as several universities outside of Spain. This will be explained in more detail in the respective sections of this chapter.

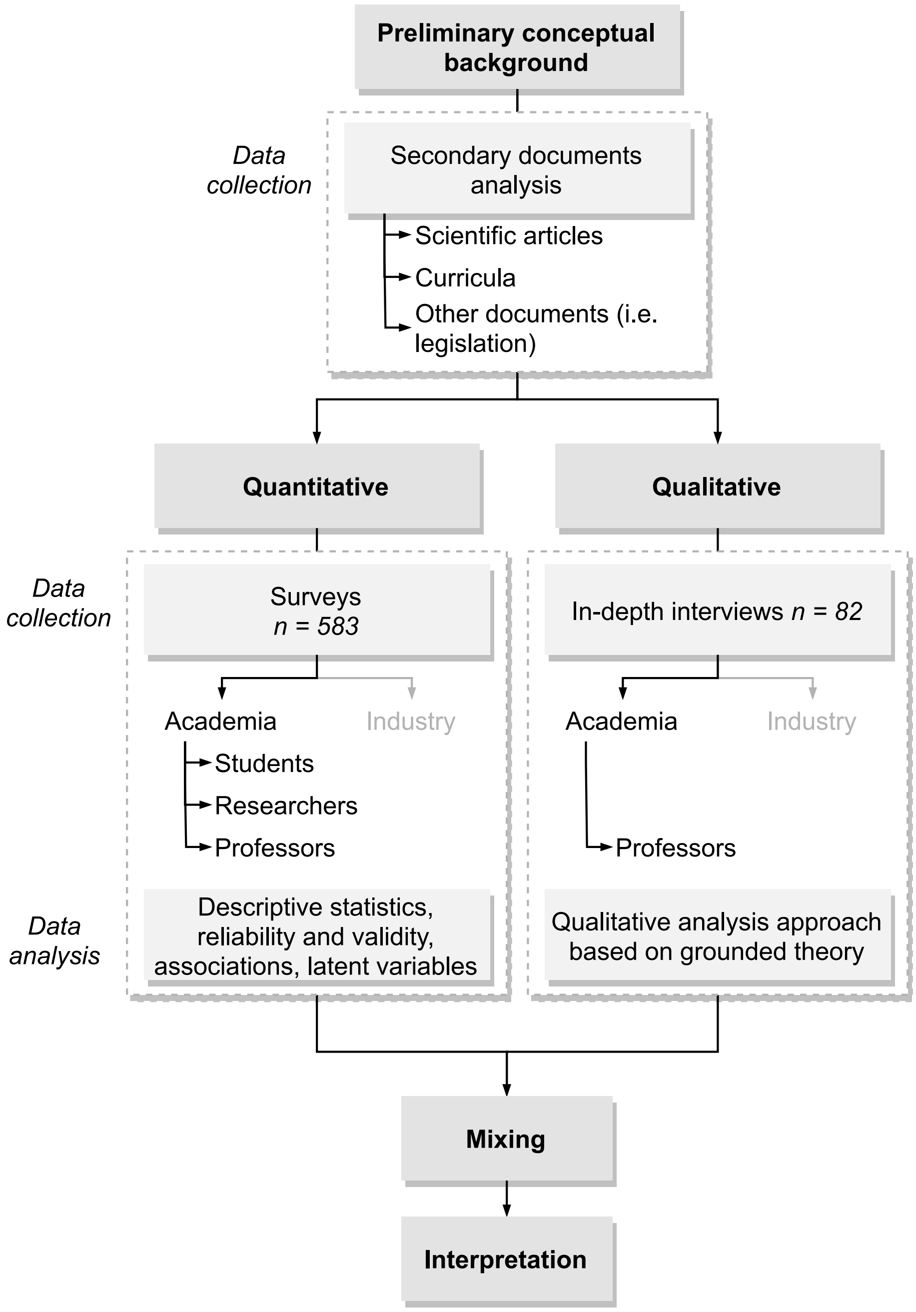

Figure 2.1. Scheme of the overall research design

2.2. Secondary documents analysis

For the different parts of the study in this dissertation, an initial literature search was performed in order to define a preliminary conceptual background. The steps followed for the search of documents and the definition of an initial conceptual background are presented below. Note that the study in Chapter 3 is specifically a literature review, and some specificities of that analysis are included there. The bibliographic searches for articles were mainly performed in the Scopus and Web of Science databases.

1. **Initial search**. At first, the combination of keywords used to search for publications was defined depending on the targeted area of the study. The titles of the studies obtained with these keywords

were scanned, noting those of interest for the study.

2. **Refining the framework**. Then, the abstracts of those studies that had been kept were read to discard those outside the scope of the study. The remaining studies were reviewed, and main issues were identified.
3. **Second search**. In the next stage of the research, the framework of the study was inductively refined, based on the results of the above-described steps. Having defined narrower themes for the study, more specific keywords could be used. Again, the titles of the studies were scanned, and the titles of those articles that fitted the study were saved.
4. **Article selection**. Finally, the previous searches led to an initial selection of articles whose titles matched the objectives of the study. In a further selection process, the abstracts were then read in order to ensure their suitability for the review.
5. **Analysis**. After the previous step, the selected articles were read in-depth to complete the literature analysis.

2.2.1. Theoretical framework

The theoretical framework built for this thesis followed a systematic process. In order to analyse the social factors involved in the different stages of the lifecycle of infrastructures and to be able to establish a conceptual framework, the methodology followed was a top-down approach. Since the main academic areas under study were civil engineering and social sciences and humanities, these fields were broken down into their respective subfields in order to be able to describe in detail the specific relationships between civil engineering and social sciences and humanities.

In order to perform a more effective review of these relationships, a general classification scheme of the subfields within civil engineering and social sciences and humanities was constructed based on already existing categories.

In the first place, the UNESCO nomenclature for fields of science and technology was used. This nomenclature divides the scientific categories into fields (general sections), disciplines (speciality groups within the fields) and subdisciplines (most specific elements of the nomenclature). The fields that were screened within the UNESCO nomenclature are ‘‘Earth and Space Sciences’’, ‘‘Agricultural Sciences’’ and ‘‘Technological Sciences’’ (code numbers 25, 31 and 33 respectively) for civil engineering and ”Anthropology”, ”Demographics”, ‘‘Economic Sciences”, ”Geography”, ”History”, ”Juridical Sciences and Law”, ”Linguistics”, ”Pedagogy”, ”Political Science”, ”Psychology”, ”Science of Arts and Letters”, ”Sociology”, ”Ethics” and ”Philosophy” (code numbers 51, 52, 53, 54, 55, 56, 57, 58, 59, 61, 62, 63, 71 and 72 respectively) for the social sciences and humanities. From these, the disciplines that were of interest for this thesis were selected.

Additionally, in order to check the exhaustiveness of the different groups of disciplines built, the classification made by international-level or regional-level professional associations were checked. Namely, the ASCE and the ICE for the civil engineering classification and the International Sociological Association (ISA) and the American Sociological Association (ASA) for the Sociology classification.

As a result, on the one hand, the subdisciplines that were established for civil engineering were: transport, water technology, energy technology, environment technology, urban planning, buildings, natural hazards, construction management, construction technology and materials technology; nevertheless, the four last categories were considered to be already included in the previous categories and for this reason only the first six subdisciplines were contemplated in the present thesis.

On the other hand, the subdisciplines established for the social sciences and humanities were: culture and history, behaviour and mind, communication and interaction, socioeconomics, juridical sciences, life and health, politics and policy making, social problems, social groups, ethics and philosophy, arts, education and innovation.

Tables 2.1 and 2.2 show the classification indicated above, together with their taxonomy and their corresponding UNESCO codes.

Table 2.1. Taxonomy of each field of civil engineering and corresponding UNESCO's nomenclature codes

Civil engineering dimension	***Keywords***	***UNESCO codes***
Transport	Bridges, harbours, highways, waterways, railway, roads, tunnels, traffic, urban transit, railroad	3305, 3323, 3327, 3329
Water technology	Reclamation of water, sanitation, sewage and sewers, dams, drainage, irrigation, water purification and supply	3102, 3305, 3308
Energy technology	Power technology, power generation, power distribution, power transmission, unconventional sources of energy	3322
Environment technology	Air pollution control, industrial wastes, pollution engineering, radioactive waste disposal, refuse disposal, solid waste management, water pollution control	3308
Urban planning	Land use, regional development, urban environment, urban-rural relations, community organisation	3305, 3329
Buildings	Houses, industrial buildings, commercial buildings, public buildings, skyscrapers	3305

The process of reviewing the literature for the taxonomy fields created was implemented in two steps. First of all, papers relating the fields of civil engineering and social sciences and humanities in more general and theoretical terms were searched. Secondly, publications regarding more specific topics (those within the subfields) were searched. This was performed by searching in databases publications using the following protocol: (TITLE-ABS-KEY("Civil engineering keyword" AND "Social science keyword*") AND ALL ("civil engineering")). After identifying all the publications to be included in the review, the categories established were analysed to see whether they were adequate or not, in which case they were to be modified and the database search done again.

After performing the database search as detailed in 2.2.1, more than 13000 references were found. However, in spite of the large amount of literature that was found, from screening the title and the abstract in the end a total of 324 publications was reviewed. The difference between identified and reviewed publications is so significant mainly due to the existence of homonyms for some of the keywords used such as training, which can also be used in engineering in the field of artificial intelligence or such as building, which can also be used in other contexts besides civil engineering. Of the selected publications, less than 1% belong to the period between 1970 and 1985, 17.3% were published between 1986 and 2005 and 82.1% between 2006 and 2019.

Table 2.2. Taxonomy of each field of social sciences and humanities and corresponding UNESCO's nomenclature codes

Social sciences and humanities dimension	***Keywords***	***UNESCO codes***
Culture and history	Culture, history, ethnics, religion, symbolism, tradition	5101, 5501, 5502, 5503, 5504, 5505, 5506, 5599, 5402, 6301
Behaviour and perception	Behaviour, mind, psychology, emotion, personality, social perception, anthropology, attitude, behavioural response, judgement	6101, 6102, 6103, 6014, 6105, 6106, 6107, 6108, 6109, 6110, 6111, 6112, 6113, 6114, 6199
Communication and interaction	Social communications, social interactions, participation, information provision	5701, 5702, 5703, 5704, 5705, 5799, 6308
Socioeconomics	Economics, economic activity, economic development, economic geography, socioeconomics, economics of technological change, industrial organisation, international economics, organisation and management of enterprises, sectorial economics	5301, 5302, 5303, 5304, 5305, 5306, 5307, 5308, 5309, 5310, 5311, 5312, 5399, 5401, 6306
Juridical sciences	Law, regulations, national law, legislation, tribunals, jurisprudence, international law	5601, 5602, 5603, 5604, 5605, 5699
Life and health	Quality of life, well-being, mental health, physical health, life course, safety, medicine, medical sociology	6306
Politics and policy making	Politics, policy making, resilience, governance, social policies, public administration, political institutions, policy sciences, international relations	5901, 5902, 5903, 5904, 5905, 5906, 5907, 5908, 5909, 5910, 5999
Social problems	Social development, poverty, inequality, social conflict, war and peace, social security, safety, crime, delinquency, disease, famine, globalisation	5103, 6304, 6307, 6310
Social groups	Social groups, tribes, women, children, youth, elder, casts, elites, family, social stratification, social classes, human geography, regional geography	5102, 5103, 5403, 5404, 6309, 6311
Ethics and philosophy	Ethics, social philosophy, moral, justice, classical ethics, ethics of individuals, group ethics, general philosophy	7101, 7102, 7103, 7104, 7199, 7201, 7202, 7203, 7204, 7205, 7206, 7207, 7208, 7299
Arts	Architecture, arts, visual appearance, aesthetics	6201, 6202, 6203, 6299
Education and innovation	Education, educational methods, training, pedagogy, innovation	5801, 5802, 5803, 5899

2.2.2. Civil engineering curricula

Civil engineering curricula in universities around the globe were analysed to determine how each institution considers the social pillar in their syllabuses. A total of 100 universities were examined. The chosen institutions are in the top one hundred in the QS ranking in the field of structural and civil Engineering. The complete list of universities analysed can be found in Appendix A, together with their respective positions in the ranking.

To interpret how social issues are included in the respective civil engineering curricula, six leading indicators were gathered for each undergraduate programme. These indicators were as follows:

- **Ranking position and score**: the ranking position of each university in the field of Civil and Structural Engineering was compiled. Besides, the scores obtained in the overall index and its indicators (academic reputation, citations per paper, h-index citations and employer reputation) were also gathered.
- **Obligatoriness**: whether social sciences and humanities subjects are obligatory or not in the curriculum of the programme.
- **Type of subject**: whether the social sciences and humanities subject is a core subject or optional.
- **Year(s)**: academic years during which students take social sciences and humanities subjects.
- **Percentage of credits**: the proportion of social sciences and humanities credits to the total amount of credits.
- **Field taught**: field of the social sciences and humanities subject. The framework in Josa and Aguado 2019 was used to classify the different fields.

Apart from the previous indicators, qualitative information was also gathered on the specific contents of the social sciences and humanities subjects. The course descriptions, objectives and competences were examined whenever such information was available. The framework from Boarin et al. (2020) was adapted to analyse the courses according to their level of focus on social sciences and humanities. In this framework, they classify subjects as having either a primary, a tangential, a possible, or no focus on sustainability. Because of the complexity of judging whether a subject had a tangential or a possible focus on social aspects in some cases, the following three categories were used as part of this research to characterise the different subjects:

- Courses with a **primary focus** on social aspects. Courses that are specifically designed to address issues in the social sciences and humanities.
- Courses with a **possible focus** on social aspects. Courses in which social aspects are not the main focus, but some attention to them is possible. Such attention may differ depending on the professor. For instance, this could comprise a course on sustainability or impact assessment whose focus might only be on environmental aspects or on both environmental and social aspects.
- Courses with **no focus** on social aspects. Courses that do not address any issue within the social sciences and humanities.

The data for each of the previous elements were obtained from the official websites of the universities being analysed. However, 19% of universities studied did not have information available on all the indicators. In these cases, the corresponding university was discarded from the analysis. In the end, a total of 81 programmes from different universities were analysed. These programmes belong to universities in a total of 29 countries located in 5 world regions: Asia, Europe, North America, Oceania, and South America.

2.2.3. Legal and institutional frameworks

The quality and status of academic programmes may be maintained through their accreditation and assessment. In fact, accrediting models and assessment processes can influence engineering education systems at different levels. Namely, at internal, external, national, regional, or even international levels (Patil and Codner, 2007). This is why in this thesis, the main accreditation bodies at either national, regional, or international levels were examined. The accreditation criteria were analysed qualitatively. The aspects considered for analysis were the requirement of subjects or contents in areas within the social sciences and humanities as well as consideration of transferable skills (such as teamwork or leadership).

To review existing accreditation systems, apart from searching for specific accreditation systems in different countries, online databases were searched with the keywords “engineering education” and “accreditation”. The publications that were found to be useful for this research were Agbool and Elinw (2013), Gorham et al. (2003), Koehn (2001), Patil and Codner (2007), Prados et al. (2005). In the end, at an international level, the accreditation bodies that were selected were the Accreditation Board for Engineering and Technology (ABET) and the European Network for Engineering Accreditation (EUR-ACE). At a national level, the bodies examined were Engineers Australia, Engineers Canada, National Board of Accreditation of India, Japan Accreditation Board of Engineering Education, Institute of Engineers Singapore, Accreditation Board for Engineering Education of Korea, Engineering Accreditation Council of Malaysia, and Institute of Engineering Education Taiwan.

Professional and engineering education institutions also play an important role in reflecting the needs of practitioners and making recommendations to shape the engineering studies curricula accordingly. Hence, apart from accreditation criteria, suggestions by two well-known civil engineering professional institutions were considered: the ASCE and the ICE. As for engineering education institutions, the stances taken by the European Society for Engineering Education (SEFI) and the American Society for Engineering Education (ASEE) were examined.

2.3. Quantitative analysis: a survey of perceptions towards of the relationship between civil engineering and social sciences and humanities

This subsection documents the quantitive research structured around a survey of perceptions towards the relationship between civil engineering and social sciences and humanities. It introduces the survey design, data collection and analysis. A copy of the survey can be found in Appendix B.

2.3.1. Survey design

Figure 2.2 shows the process that was followed from the design to the closure of the online survey. First of all, the objectives of the survey and its scope were established. In particular, the goals were five: (1) to obtain an approximation about the current state of the social perception of civil engineering and of the areas in which civil engineering contributes to society; (2) to obtain an approximation about the current state of implementation of social aspects in the decision-making processes throughout the lifecycle stages of infrastructures; (3) to detect strengths and weaknesses in social commitment of faculties, which could be helpful in future research lines to elaborate a proposal for improvement; (4) to get to know the barriers and catalysers for the implementation of social aspects in the training of civil engineers; (5) to understand the differences in social awareness among different stakeholders. As for the scope, it was defined that the targeted participants would be primarily working and/or studying in the same region (Barcelona).

After defining the objectives and scope, the specific participants that would be answering the questionnaires were defined as will be explained in Section 2.3.2. Apart from the participants, it was necessary to define the indicators needed for the analysis. As the literature emphasises, using a robust and sound set of indicators is a relevant way of better defining the scope of the questions (Artino et al., 2014, Jain et al., 2016). After determining an initial set of indicators and questions for the survey, the survey had to be validated (Artino et al., 2014, Jain et al., 2016).

The validation of the survey was made in two successive stages. First of all, it was reviewed by an external committee. This external committee was chosen based on the interest group to which the survey was addressed. In the end, eight external people participated in the review of the survey: three professionals, four professors and program directors and one PhD student. After receiving the

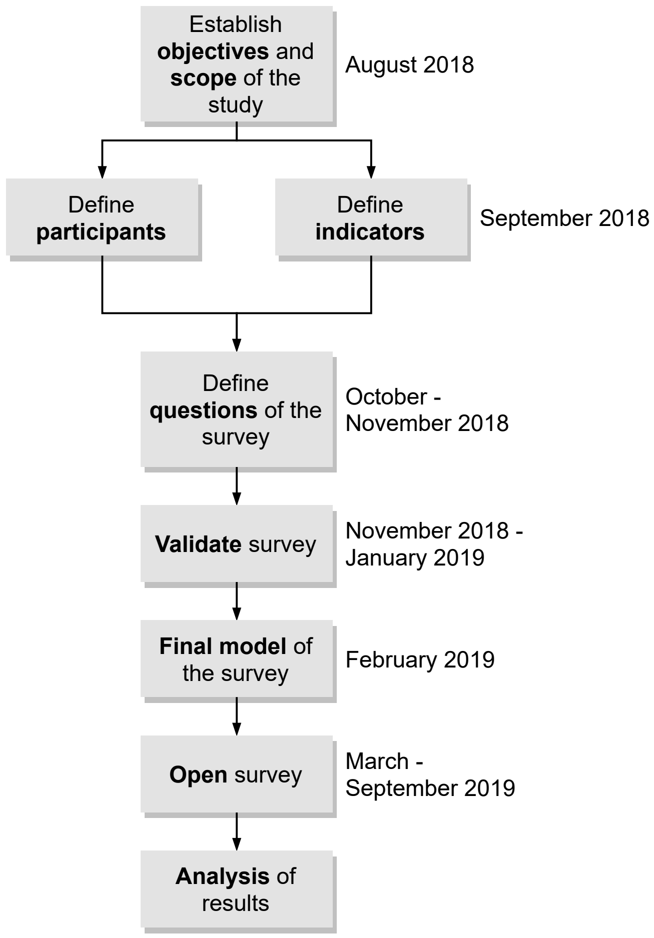

Figure 2.2. Process followed for the survey and dates corresponding to each stage

comments of these participants and correcting the survey accordingly, a closed version of the survey was sent to 42 students for them to answer it.

After this step, only slight variations were necessary. In the end, the final structure of the survey followed the structure of five main blocks as outlined next:

- **Profile of the respondents**.
- **General questions on the field of civil engineering**. Questions about the relationships between civil engineering and the social sciences from a broad perspective.
- **Specific questions on subfields of civil engineering**. Questions about the relationship between different fields within civil engineering (transport, energy, water, buildings, environmental technology, urban planning...) and different social aspects.
- **Education**. Questions regarding social aspects that are currently included and that should be included in civil engineering education, as well as methodologies to include them.
- **Profession**. Questions about social skills, both soft and hard, that are necessary and used in the day to day of civil engineering professionals.

Because the survey targeted different groups, some of the questions differed for each group to allow for a deeper understanding of specific areas with which the stakeholders could be more familiar. In Appendix B, the previously presented structure of the survey is shown in more detail and, additionally the specific questions posed to each of the groups are included.

2.3.2. Research sites and participants

Various groups of potential participants for the study were initially identified. On the one hand, there were stakeholders somehow connected to civil engineering. This included individuals from both academia (students, professors and researchers) and industry. On the other hand, there were stakeholders outside of civil engineering who could give insights on how the profession is perceived from an external point of view. For this dissertation, the focus was set on the former because of their importance (Kettunen, 2015) and because considering both internal and external stakeholders would go beyond the defined objectives.

Regarding the research settings, data at two different levels were defined: national and international. Data at an international level was not obtained through the survey, but through and interview campaign, which will be described in more detail later. Hence, data at a national level was collected using the survey. In particular, within academia, surveys were distributed among students, professors and researchers of the Technical University of Catalonia. Within the industry, professionals from different fields and at different stages of their career were selected as possible respondents. In all cases, they were working in Barcelona or its surroundings.

2.3.3. Data collection

The survey was created using the Survey Monkey platform, and it was circulated both on paper and online. Answers were received between 20th January 2019 and 5th September 2019. The survey was sent out to all stakeholders involved in civil engineering education at the Technical University of Catalonia: undergraduate students, master students, PhD students, researchers and professors. Furthermore, the survey was also sent out to civil engineers working in the same city as the university.

The way in which each participant group was contacted is described next:

- **New students**: the welcoming session for new civil engineering students was attended by the doctoral candidate, and specific time was allocated for students to answer the questionnaire.
- **Undergraduate and graduate students**: professors were contacted for them to distribute the survey among their students. In most cases, the doctoral candidate was given some class time for students to answer the survey, and in the remaining cases the professor sent the survey directly to students so that they could answer it in their free time.
- **Professors**: they were contacted individually (either in person or by email) with a request to answer the survey and to distribute it to their colleagues.
- **Practitioners**: several key engineering organisations were contacted so that they could distribute the survey among their colleagues or company.

In the end, a total of 583 questionnaires were collected. Among the respondents, 16.2% were new students, 21.7% undergraduate students, 28.6% graduate students, 16.6% researchers and/or professors, and 16.8% practitioners.

2.3.4. Survey analysis

The steps suggested by Creswell (2012) were followed in the process of analysing the quantitative data obtained from the survey, namely:

1. **Preparation of the data** for analysis. It was decided that survey results would be analysed using R. Where necessary, non-numeric responses were scored. For instance, questions where respondents had to choose among different items in a scale, a numeric value was assigned. An example would be: 5="Very important", 4="Fairly important, 3="Important", 2="Slightly impor-

tant",1="Not important". Besides scoring the data, data was cleaned by inspecting the existence of outliers and assessing it for missing data.

2. **Data analysis**. In general terms, for each block of questions, a descriptive analysis was conducted, followed by a reliability and validity analysis, and finally, latent variable analysis. The survey had several questions, and some of them differed in terms of the type of indicator. This is the reason why various analysis methods were necessary. The specific methods that were used are described in further detail in the following subsections. Besides, those methods that require some further description are described in more detail in Appendix A.
3. **Reporting of the results** using tables, figures, and the discussion of key results.
4. **Interpretation of the results** from the analysis of the data.

2.3.4.1. Descriptive analysis

In the analysis of the survey responses, descriptive statistics were used with the main purpose of summarising data and making it easier to assimilate the information. For this, three different elements were utilised:

- Tables and graphs.
- Measures of central tendency. Descriptions of the centre of the data were mostly done using the mean, which is the sum of the observations divided by the number of observations, and the median, which reflects the observation that falls in the middle of the ordered sample.
- Measures of variability. The main measure of variability that was used was standard deviation, which reflects the amount of variation of a set of values.

2.3.4.2. Reliability and validity

Even though reliability and construct validity are two different qualities, they are interconnected. If a survey's reliability is not good, then it does not validly measure the construct that is intended to be measured. However, a survey can also have high reliability but poor validity since it can be measuring the wrong construct. Hence, reliability is not a sufficient condition for validity.

In particular, in statistics, reliability refers to the consistency of a measure. There are three types of consistency:

- Test-retest reliability, which is related to the fact that the results obtained in one test are both representative and stable over time. Therefore, the test should be able to be reliably replicated in the same situation and population.
- Internal consistency, which measures the consistency of individual items of a test.
- Inter-rater reliability, which measures the consistency of the same test answered by different people.

Two main methods were used in order to check the reliability of the results in the present study: the Cronbach alpha coefficient and measures based on Item Response Theory[1].

Validity is the extent to which the scores of a measure represent the variable that they intend to measure. Analyses of validity are usually divided into different types, which, in addition to reliability, give evidence to be considered when the validity of a measure is judged. Three basic kinds of validity are face, content, and criterion validity.

- Face validity, which refers to the extent to which a test succeeds in measuring what it is intended to measure.

[1] More details on these elements, as well as on the specific models that have been developed in the context of IRT and that are used in the dissertation can be found in Appendix A.

- Content validity, which is related to refers to the extent to which the items of a test are representative of the entire domain of the trait that the test aims to measure.
- Criterion validity, which is related to the extent to which a measurement tool predicts an outcome for another measure.

In particular, the degree of correlations among a set of variables can be investigated using the **Cronbach alpha coefficient** (Cronbach, 1951). According to several references, this coefficient is the most common estimate of internal consistency of the items in a survey (Boscarino et al., 2004, Miller, 1995). The purpose of this coefficient is to assess how well a set of items measures a single unidimensional phenomenon.

Cronbach's alpha can be obtained from the number of test items, and the mean inter-correlation among the items as shown in Equation 2.1.

$$\alpha_c = \left(\frac{N}{N-1}\right)\frac{\sum_{i\neq j} cov(x_i, x_j)}{var(x_o)} = \left(\frac{N}{N-1}\right)\left(1 - \frac{\sum_j var(x_j)}{var(x_o)}\right) \tag{2.1}$$

In **IRT-based measures**, reliability depends on the estimated score, and it, therefore, depends on every response. For every response pattern, it equals the following (Equation 2.2):

$$\alpha_{IRT} = 1 - SE^2 \tag{2.2}$$

where SE represents the standard error of the estimated ability (θ) score. The average reliability can be obtained by using the mean of the SE as shown in Equation 2.3.

$$\alpha_{IRT} = 1 - mean(SE)^2 \tag{2.3}$$

2.3.4.3. Associations between variables

When analysing responses from questionnaires, it may be relevant to examine whether there exist associations between two or more variables. There exist various methods to determine such a measure of association. The method used depends on the characteristics of the data, such as whether it is continuous, ordinal, or categorical.

In this dissertation, three main methods were used to examine the association between variables, and they were applied, taking into consideration the different types of indicators available. These were the chi-square test, the Kruskal-Wallis H test, and the Friedman test. They are briefly presented below.

Chi-square tests are frequently used to test the statistical independence of a population. Two variables are said to be independent if their distributions differ from each other given the results of the test. The hypotheses tested are:

H_0: the variables are statistically independent.
H_1: the variables are statistically dependent.

The test statistic for the null hypothesis summarises how close the expected frequencies fall to the observed frequencies, and it is computed as presented in Equation 2.4.

$$\chi^2 = \sum \frac{(f_o - f_e)^2}{f_e} \tag{2.4}$$

Where f_o is the observed frequency (Corresponding to the observed counts in the cells), and f_e is the expected frequency if no relationships existed between the variables. It is equal to the product of the row and column totals for each cell, divided by the total sample size.

The value of this statistic can be evaluated by examining the p-value. To determine whether the variables are independent, the p-value is compared to the significance level. Usually, a significance level of 0.05 is used, which indicates a risk of 5% of concluding that there is an association between the variables when in fact there is no association. If the p-value is equal to or below the significance level, H_0 can be rejected, meaning that there is a statistically significant association. If the p-value is above the significance level, we fail to reject H_0 and therefore cannot conclude that the variables are associated.

The **Kruskal-Wallis H test** is a non-parametric test that can be used to determine if there are statistically significant differences between two or more groups of an independent variable on a continuous or ordinal dependent variable. It is considered to be a non-parametric equivalent of the one-way ANOVA.

The **Friedman test** is also a non-parametric test, and it is used to detect differences in responses across multiple test attempts. It is considered to be similar to the parametric repeated measures ANOVA.

2.3.4.4. Latent variable analysis

Latent variables are variables that cannot be directly observed. These variables are assumed to affect other variables that are observable, which are referred to as manifest variables and which can be obtained from the responses to surveys. A discussion about a number of ways in which latent variables have been defined in the literature and differentiated from observed variables can be found in Bollen (2002).

Latent variables are typically included in models called latent variable models. Models are simplified descriptions of the structure of the observations. Their purpose is to provide a simple explanation of the phenomenon that is being investigated, and that is consistent with the observations. As described by Everitt (1979), the model can be summarised as in the next equation:

$$data = model + residual \tag{2.5}$$

In this expression, the model is the latent and simplified structure of the data, whereas the residual is the difference between the data and the model. If the residual contains further patterns or structure, then the model still needs to be finetuned.

Latent variable models are usually classified according to two main factors (Bartholomew, 2015, Everitt, 1979): the nature of the response variables and of the latent variables, which can be discrete or continuous. Besides, some authors further incorporate one factor, namely whether individual covariates are included or not.

There exist several different tools for exploring latent variables underlying data, such as responses to survey items. The following are some of the most well-known latent variable models: multiple regression, limited dependent variable, factor analysis, latent curve, Item Response Theory, latent class, or structural equations.

In this thesis, four main latent variable models were used. They were factor analysis, Mokken scaling, Akaike criterion, and Item Response Theory. More details on these can be found in Appendix A.

2.4. Qualitative analysis: expert interviews

As part of the mix of research strategies used, the present study used as well an adapted qualitative research framework. Expert interviews were collected in order to obtain additional in-depth data on the perceptions of academics towards various social concepts and the introduction of relevant content from the social sciences and humanities in the education of civil engineers. This final section of the methodology chapter details the way in which these interviews were designed, conducted, and analysed.

2.4.1. Qualitative analysis method

In 1967, Glaser and Strauss first articulated the strategy of developing theories of social processes based on data (Glaser and Strauss, 1967). The purpose of this subsection is to introduce the reader to the main method that guided the interview study design: the grounded theory method. According to Glaser and Holton (2004), grounded theory (GT) can be defined as “a set of integrated conceptual hypotheses systematically generated to produce an inductive theory about a substantive area” (Glaser and Holton, 2004, p. 3). It needs to be noted that, in this thesis, some of the features of the method were borrowed as an orientation to conduct the design and analysis of the expert interviews, but it was not fully applied.

The evolution of grounded theory has given rise to three different methodological strands: the emergent GT (Glaser and Strauss, 1967), the systematic GT (Strauss and Corbin, 1990, 1998, Strauss, 1987), and the constructivist GT (Charmaz, 2006). The latter two are extensions to the original GT by Glaser and Strauss. Note that some authors (Chun Tie et al., 2019, Rieger, 2019) have referred as the traditional or classic GT to the emergent GT, and as the evolved or Straussian GT to the systematic GT.

The following are the main features that characterise these genres:

- *Emergent GT*: it acknowledges that the goal of GT is to generate a conceptual theory that considers a behaviour pattern that is relevant and problematic for those involved.
- *Systematic GT*: it is founded on symbolic interactionism, which is a sociological perspective that relies on the symbolic meaning that people ascribe to the various social interaction processes. Symbolic interactionism addresses the subjectivity of the meaning that people place on elements (objects, events, behaviours...) based on what they believe is true.
- *Constructivist GT*: it is based on constructivism, and it focuses on how participants construct meaning in connection with the area under study.

Even though there are common features among the three GT genres, there are several factors that distinguish each approach from the other. According to Chun Tie et al. (2019), these distinct features are the researcher’s philosophical position, the use or not of literature, and the method utilised for coding, analysis and development of theory. Table 2.3 presents a summary of these distinguishing characteristics for the three genres. For further comparisons between the three approaches, the reader is referred to Hunter et al. (2011a,b), Rieger (2019).

Having said this, the whole research process that was followed for the interviews is illustrated in Figure 2.3. In the following subsections, the fundamental steps of the procedure followed are outlined, including the selection of research sites and participants, data collection method, the procedure for data analysis, and items checked to ensure the works’ rigour.

Table 2.3. Comparison of the three genres of grounded theory. Adapted from Hunter et al. (2011b), Sebastian (2019)

		Emergent GT	Systematic GT	Constructivist GT
Underlying philosophy		Soft positivism	Post-positivism and symbolic interaction-ism	Constructivism and symbolic interaction-ism
Use of literature		No initial literature re-view; literature is used at the very end.	Literature is used appropriately at every stage.	Literature is used at every stage, and a lit-erature review is com-piled.
Research questions		Emergent, there are no pre-set questions. They develop during data analysis.	They are partially vague in the begin-ning, and become more specific during data analysis.	Research questions influence data collec-tion, and they can be modified during data collection.
Theory creation		Substantive theory is created after the com-pletion of the research study. It can be evalu-ated through fit, work, relevance, modifiabil-ity.	Substantive theory is created after the com-pletion of the research study. It can be evalu-ated using validity, reli-ability, efficiency, sen-sitivity.	The theory con-structed is an inter-pretation and not an exact representation. It depends on the researcher's expe-rience. Theory is situated in the context (time, place, culture).
Coding framework		Coding emerges from the content of the data in order to discover the theory.	More meticulous and specified process.	Flexible and more open process, without prescriptive ap-proaches.
Coding	**Initial**	Open coding	Open coding	Initial coding
	Intermediate	Selective coding	Axial coding	Focused coding
	Advanced	Theoretical coding	Selective coding	Theoretical coding

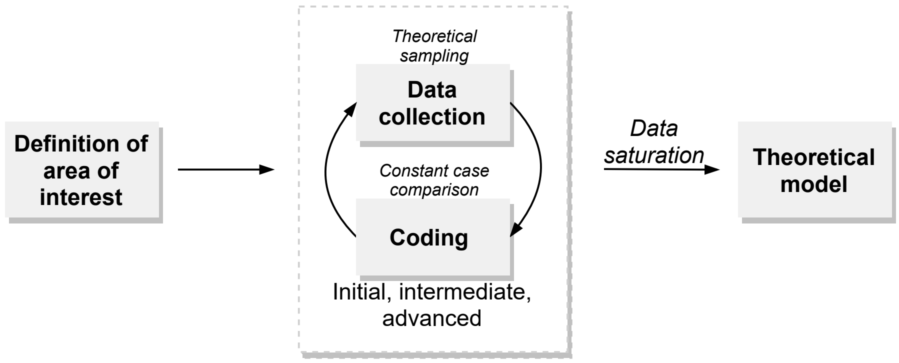

Figure 2.3. Research process followed in the interviews

2.4.2. Research sites and participants

An important aspect related to the research process is iteration and constant comparison. In the grounded theory method, collecting data and analysing intertwined processes. As Glaser and Strauss (1967) wrote, the researcher "jointly collects, codes and analyses his data and decides what data to collect next and where to find them, in order to develop his theory as it emerges" (Glaser and Strauss, 1967, p. 45). Thus, in grounded theory, the sampling process is entirely shaped by the emerging theory and is therefore referred to as "theoretical sampling".

Throughout the process, civil engineering schools were purposefully chosen. Purposeful sampling is a term coined in qualitative sampling, where individuals and sites are selected intentionally to analyse the central phenomenon (Creswell, 2012). There exist several strategies that lie within the purposeful sampling method, such as representative, extreme, maximal variation, critical, or homogeneous case sampling (Creswell, 2012, Yin, 2018).

In this thesis, research sites were chosen following maximal variation sampling, where sites are sampled that differ in some traits or characteristics. Besides, critical sampling strategy was also emplyed to study critical cases of civil engineering schools that either did not include any social aspect at all, or that had social aspects completely integrated in their programmes. Regarding the choice of participants within each research site, a combination of typical, homogeneous and snowball sampling was employed as is explained next.

Initially, the following aspects were considered when choosing possible interviewees: taught and expertise fields (transport, energy, water, urban planning, buildings and environmental technology), gender (to try to keep a balance between male and female interviewees) and different position levels (researchers, lecturers, professors...).

Professors and researchers working at the civil engineering schools were the focus of the research. Hence, they were not necessarily civil engineers. First of all, theoretical sampling was used to select participants based on the fact that their input could be of particular interest to answer the research questions posed (see Section 1). Thus, professors and researchers whose profile on the faculty website showed a particular interest in social topics (such as ethics, cooperation, development, etc.) were contacted. In addition to this, it was necessary to contrast these interviewees' input with professors that did not appear to have a specific stance towards social topics in civil engineering from the information that could be gathered from the universities' websites.

Besides theoretical sampling, negative case analysis and the flip-flop technique were used for participants' selection. First, in negative case analysis, an initial hypothesis is developed. Then, elements of the data that do not support or appear to contradict these explanations are searched for and discussed (Lincoln and Guba, 1985). In this study, this was done by identifying participants that may have contradicting positions and by specifically searching the data for elements that did not support certain findings. Second, to ensure reliability, Corbin and Strauss (2008) recommend using the flip-flop technique, in which arising concepts are examined from a different perspective in order to make clear its most significant properties. This is done by "turning a concept inside out by looking at opposite extreme conception of a concept to highlight its properties".

On top of the above, most of the interviewees were asked at the end of the interviews if they considered that there was someone in their faculty that could be interested in being interviewed or whose opinion could be relevant for the study. This is referred to as snowball sampling in the literature.

Recently, authors have called for paying explicit attention to the impact that race and gender may have on research results. However, in the present study, aspects such as socioeconomic status or self-identified racial identity were not collected to ensure the participants' confidentiality and comfort.

In both the international and national cases, the request for the participation of the potential interviewees was made by email. The request described the authors' interest in the inclusion of social aspects in civil engineering education. It included a copy of the participant information letter and a copy of the informed consent form. These documents included information about the project's objective, how participants had been selected, duration, risks, benefits, incentives, confidentiality, sharing of results, and the right to refuse to do the interview.

As a note, Creswell (2014) recommends interviews with up to ten people for phenomenological studies. To ensure the researchers' availability for the interviews, each time, emails for around fifteen interviewees were sent with time separations of two weeks. The number of fifteen interviewees was chosen to consider potential rejections by the contacted people. Reminders were sent after three to four weeks when the contacted people did not reply.

2.4.2.1. International interviewees

Information about the contacted people was obtained from the websites of the civil engineering schools chosen. Schools were chosen among the universities that were as well examined in the analysis of civil engineering curricula (as explained in section 2.2.2).

The iterative process that took place as described above involved contacting groups of around 25 people every two weeks, approximately for four months. If no reply was received after one month, reminders were sent every 30 days for a maximum of three times. In the end, 206 people from 19 different institutions were contacted. Among them, 59 (28.6%) agreed to be interviewed, 27 (13%) declined the request, and the remaining 120 did not reply.

Table 2.4 shows details of the participants. In order to maintain their anonymity, only general details of the interviewees are provided.

Table 2.4. Details of the participants for the international campaign

		Participants		
Country	**University**	**Female**	**Male**	**Total**
United Kingdom	Imperial College London, University College London	3	1	4
Sweden	Chalmers University of Technology	2	2	4
Switzerland	ETH Zürich	1	4	5
Singapore	National University of Singapore	0	2	2
Hong Kong	Hong Kong University, Hong Kong Polytechnic University	0	2	2
China	Tsinghua University	1	0	1
Taiwan	National Taiwan University	0	3	3
India	Indian Institute of Technology Bombay	1	3	4
Australia	University of New South Wales	3	7	10
Chile	Pontificia Universidad de Chile	0	3	3
Brazil	University of São Paulo	4	7	11
Canada	University of British Columbia	0	2	2
United States	Georgia Institute of Technology	2	0	2
South Africa	University of Pretoria	0	4	4
Kenya	University of Nairobi	0	2	2
		17	42	59

2.4.2.2. Interviewees in Spain

Three civil engineering schools from Spanish polytechnic universities[2] were chosen. To maintain the anonymity of the institutions and the participants, only the general details necessary to support the research findings will be provided. Hence, these three institutions will be referred to as A, B, and C.

[2]Note that in Spain, as will be discussed in the following sections, because of traditional reasons, most civil engineering schools are called, with minor variances, "*Escuela de Caminos, Canales y Puertos*".

The schools' websites at A, B, and C were examined to find profiles of researchers and professors that could be of interest to the project. In the end, in total, 54 people were contacted, among which 23 accepted (42.5%), 3 declined (5.5%), and 28 (52%) did not answer. The distribution of participants from each institution is shown in Table 2.5 divided by sex. The proportional representation of male and female interviewees can be considered to be representative of the proportions existing in these faculties. The majority of the participants were native Spanish.

Despite the effort to recruit the same number of interviewees from each faculty, it was primarily members of faculties A and B that responded to the call. The reason for which there were these differences is unknown, but it may be possible that there were external restrictions due to teaching commitments. In fact, it should be noted that the interview requests were sent during the second wave of the COVID-19 in Spain, which certainly posed some level of pressure on every sector. Hence, even though this has not been proved, there may have been a selection bias as those who agreed to participate in the interview may have been particularly interested and concerned about this topic.

Table 2.5. Details of the participants for the national campaign

	Participants		
Institution	**Female**	**Male**	**Total**
A	2	10	12
B	1	1	2
C	6	3	9
	9	14	23

At this point, it needs to be noted that professors were contacted in phases so that the process and questions asked could be adapted to the emerging topics from interviews (constant comparison). As more data was gathered, less new information was obtained, leading to a data saturation point. As Bogdan and Biklen (2007) describe, data saturation refers to a point in which the information obtained from the data collected becomes repetitive or redundant. According to Gasson (2011), when the point of theoretical saturation is reached, it should be possible to develop a formal theory from the results. In the present case, after the development and analysis of around 20 interviews, not many new codes were incorporated into the codebook. This is due to the fact that the categories had largely developed after the first 20 interviews, and a data saturation point had been reached.

2.4.3. Data collection

Even though authors emphasise the importance of interviews taking place at the participants' choice so that they feel comfortable (Kvale, 2007, Sandbergh, 1997), video calls were chosen as the interview means in all cases because of practical reasons in the case of international interviewees. In the case of Spanish interviewees, besides from the convenience of videocalls, restrictions posed by COVID-19 did not allow to have in-person meetings.

Most of the interviews conducted were recorded following the recommendations by Cohen et al. (2007), Wengraf (2001). Once the interview finished, the recording file was assigned a code number to ensure anonymity. Then, the interviews were transcribed by the doctoral candidate.

The interviews were semi-structured to allow for probing and follow-up questions (Roulston and Choi, 2018). The structure followed for the interviews to international interviewees and interviewees in Spain differed slightly, even though the overall structure was the same. The topics that were included in the interview were the ones that are shown in Table 2.6. Three main blocks of questions were prepared, an introductory one, one related to education issues, and one related to research. These blocks were preceded by a brief preliminary in which the main issues related to the protection and privacy of the participants were reminded, and the structure of the interview was presented.

Table 2.6. Overview of the design of the semi-structured interviews

Block	Topics
Preliminary information	Informed consent about recording, treatment of data, duration of the interview
Introduction	Profile of the interviewee (professional and academic path, specialisation), interest towards different areas of the social sciences and humanities, conception of the social impact of civil engineering.
Education	Introduction of social aspects in civil engineering programs, and in their own subjects, perception of the students' interests towards social topics, perception of other professors, benefits and drawbacks to the integration of social sciences and humanities in civil engineering programs.
Research	Introduction of social aspects in own research projects, possible incentives for such introduction, barriers.
Miscellaneous	Concluding remarks, current challenges and future changes in civil engineering programs.

An interview schedule was generated and used in order to guide the discussion, even though the questions were open-ended to allow for discussion on topics that had not been considered and that may be important. Appendix C presents a description of the interview protocol together with core interview questions.

In order to check the flow of the interview structure before the start of the real interviews, two pilot tests were conducted, one with a researcher and the other with a professor from the home university of the doctoral candidate, Universitat Politècnica de Catalunya.

2.4.3.1. International interviewees

Semi-structured qualitative interviews with international interviewees were conducted during a period of 4 months (April to July) in the year 2020. The interviews took approximately one hour each, except in cases in which the interviewees requested that it lasted 30 minutes due to time constraints[3].

All the interviews were recorded, except for one due to technical issues. Besides, two contacted participants explicitly asked to answer the interview through an online questionnaire, and they were provided with a link with all the questions. Apart from these two cases, all the interviews took place through video calls.

2.4.3.2. Interviewees in Spain

The interviews with interviewees in Spain were conducted over a period of four months, between November 2020 and February 2021, and their duration ranged between 40 and 90 minutes. Most of the interviews were carried out in Spanish, except for four that were conducted in Catalan at the request of the interviewee.

The interview protocol followed is the one that was provided in Table 2.6, and slight changes to the questions were made to adapt them to the different context of these interviews even when the overall structure was not modified.

[3]The average duration of the interviews was of 55 minutes.

2.4.4. Data analysis

The analytic techniques employed in this study also draw from the methods used in grounded theory (Charmaz, 2006, Glaser and Strauss, 1967) and by means of codes. Saldaña describes codes as "most often a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data" (Saldana, 2009, p. 3).

In the grounded theory method, qualitative data is analysed using the following major steps: open coding, axial coding, and selective coding. Open coding is commonly the first step, and it is used to break the data into discrete parts and create "codes" to label them. This step is meant to open the researcher up to new theoretical possibilities and force the researcher out of biases or preconceived ideas about the research. Then, axial coding aims to define a manageable number of categories used to develop a paradigm to explain the grounded theory. Differently to open coding, with axial coding, connections are drawn between codes. The last step of coding is selective coding, where all the categories are connected around one core category. This allows defining one unified theory around the research study, and the core category usually represents the central thesis of the theory.

In the present study, the interviews' analysis was carried out based on the transcripts and the notes taken during the interviews. In particular, a qualitative analysis software (Atlas.ti) was used to code the documents and develop and structure salient topics.

Apart from theoretical sampling, which was described above, constant comparison is also relevant in the analysis process for the development of a grounded theory. Constant comparison requires the researcher to examine the new data constantly and what themes and categories emerge, and how they relate to previously detected themes and categories. In the present study, elements resulting from the different interviews were continuously compared and analysed to see how concepts and meanings emerged from the data and what needed to be asked in further interviews.

2.4.4.1. Initial coding

In the first round of coding, the transcriptions were read and codes were progressively created and assigned to the information given by interviewees. In particular, long blocks of speech were broken up into smaller quotes in such a way that every quote represented a single idea. At this point, these codes were essentially descriptions of what the interviewee was saying. As Charmaz (1990) puts it, these codes need to be simple and direct words that directly come from the data.

After the first read of each transcript, a memo was created for each interviewee to help to contextualise their overall story. These memos included the most relevant remarks given by each interviewee. Besides, other memos were written during the open coding process, with reflections or questions arising from the data appeared.

Creswell and Guetterman (2018) notes the importance of tracing the process of analysis of grounded theory to ensure reliability and credibility. Hence, the codes that were created in the first coding round have been included in Table C.1 of the appendix.

2.4.4.2. Intermediate coding

In intermediate coding, the coded elements of the data are searched for relationships between them. Theories emerge when these relationships are examined, and similarities and differences are analysed. After doing the initial coding tasks, memos were examined, and the codes were analysed through network analysis. In particular, they were grouped by categories, and relationships were established among groups and subgroups of codes. By analysing data from the interviews again, the codes and categories were finetuned and strengthened (comparative case analysis, which was described above).

The codes that were created in the second coding round have been included in Table C.2 of the appendix.

During this second round of coding, some parts of the interviews that had not been coded with appropriate codes were re-assigned codes. Only a few new codes arose, but they confirmed the category structure defined, as the codes fitted well in the different categories and subcategories.

2.4.4.3. Advanced coding

In the final phase of coding, categories are integrated and refined in a way that every category relates to the core category. In the present study, the core category was connected to other categories referred to as discursive strands.

2.4.5. Quality and rigor

Verification of the rigour of the study is critical in any research process, but, in particular, it has been considered to be fundamental when applying grounded theory as this method has often been criticised for lacking rigour (Gasson, 2011). Authors have argued that qualitative research's quality and rigour can't be judged through an interpretive perspective rather than a positivist one (Gasson, 2011, Lincoln and Guba, 1985, Miles and Huberman, 1994, Miller et al., 2015).

Creswell (2012) points at six factors that characterise a high-quality grounded theory study, namely:

1. Making the process that is the object of the study explicit.
2. Developing a theory at the end of the analysis that is based on the view of the participants.
3. Making sure that there is a connection between the data, the categories generated, and the ultimate theory.
4. Showing that memoing and sampling were used as a means of generating the theory.
5. Illustrating the theoretical model developed through a visual resource.
6. Giving evidence of using a specific type of grounded theory genre (emergent, systematic, or constructivist).

It was ensured that the previous points were satisfied, and evidence of the six of them is provided throughout the present document. Besides these factors by Creswell (2012), other authors have provided specific items to verify to ensure the study's rigour (see, for instance, Gasson, 2011 or Sikolia et al., 2013). Next, the different items checked to ensure the study's quality are described, including confirmability, dependability, internal consistency, and transferability.

2.4.5.1. Confirmability

Confirmability is related to the extent to which the research design and respective results can be substantiated and confirmed. In other words, confirmability allows testing the objectivity of research. According to Krefting (1991), the researcher is responsible for ensuring confirmability by ensuring that the results of the study arise from the data and not from personal biases.

Confirmability can be ensured through a detailed audit trail performed by an external observer. In the present study, this was done by sharing the process followed and conclusions drawn with other researchers and discussing all the details with them.

In addition to the above, Lincoln and Guba (1985) say that the best way in which qualitative researchers can establish credibility is to describe the steps taken to generate the theory clearly. This is one reason why care has been taken to explain all the details of the research process.

2.4.5.2. Dependability

A study's dependability is related to whether the study process and respective results are consistent and more or less stable over time and among different researchers. Gasson (2011) recommends establishing transparent and repeatable research processes, as well as being reflexive about the position that the researcher takes. This allows minimising subjectivity throughout the process.

In this thesis, this was done by critically examining the results that were being obtained in each stage of the analysis to ensure the maximisation of objectivity. Besides, systematic steps were followed as it has been explained in this section.

2.4.5.3. Internal consistency

Internal consistency refers to the fact that research findings need to be credible and consistent, and the results need to reflect the multiplicity of the realities defining the phenomenon studied (Sikolia et al., 2013). In order to ensure internal consistency, Gasson (2011) recommends constantly re-examining the data critically and periodically employing visual techniques to examine the connections between data elements explicitly.

This was done in the present study through illustrations on pieces of paper, but mainly in Atlas.ti, with the network analysis tool, that allows placing all the memos, quotes, codes, code groups and documents in the same place and create connections between them.

2.4.5.4. Transferability

The transferability of a study is related to the internal and external validity of the research. In the context of grounded theory, internal validity examines whether the research carried out is in direct relationship with the research questions of the specific project. External validity looks at the various circumstances in which the processes and outcomes of a particular study can be applied (Malterud, 2001). As Gasson (2011) puts it, it looks at the question of "how far can the findings be transferred to other contexts and how do they help to derive useful theories?".

Authors recommend using the constant comparison method in order to ensure the transferability of findings. This was done in the present study as it was already described above. However, it needs to be noted that we do not claim that the results obtained herein are generalisable to any process at universities since the data used is bounded in a specific context.

2.5. Summary

In this chapter, the overall research framework and methodology of the dissertation was introduced. A mixed-methods approach was established as an appropriate research vehicle for this thesis due to the fact that integrating quantitative and qualitative data collection and analysis methods allows using data in a more complete and synergetic way than if only one type of data was utilised.

The chapter started by an initial overview of the methodological approach. This included the reasons for using a mixed-methods approach, as well as its main characteristics, and the choice of the analysis cases as well as participants and research settings. The two research setting set are an international level and a national one (in Spain). As for the participants, they differ for the qualitative and quantitative data collection methods. Participants of the interviews were faculty members of various civil engineering schools. For the international case, this consisted of 59 interviewees from 17 different civil engineering schools. For the Spanish case, participants were comprised by 23 interviewees from 3 Spanish civil engineering schools.

Then, the process that was followed to design the survey, collect the data, and analyse it was presented in the following section. Apart from the quantitative methods, the process followed in the case of qualitative data (semi-structured interviews) was described.

Third, the way in which the analysis of secondary documents was done was described. Such analysis was important to define robust conceptual bases for the development of the study. In addition to the general overview of the methodology followed for the analysis of the documents, the specific processes followed in the different parts of the thesis were described. More specifically, this included the steps for the development of the theoretical framework of the thesis, the way in which civil engineering curricula around the world were reviewed, and the method to analyse the legal and institutional systems shaping civil engineering education worldwide.

3

Theoretical framework

This chapter is partially based on the following article:

Josa, I. & Aguado, A. (2019). Infrastructures and society: from a literature review to a conceptual framework. *Journal of Cleaner Production*, 238. DOI: 10.1016/j.jclepro.2019.117741.

The doctoral candidate contributed 90% of the work presented here.

3.1. Introduction

It is widely accepted that impacts from human activities are generally identified with three interdependent pillars: economy, environment and society. The first two pillars, economy and environment, have received considerable attention. However, when it comes to society, the research has been rather scarce (Ahi and Searcy, 2015, Taticchi et al., 2013). According to Vallance et al. (2011), it is the difficulty involved in the definition of this construct that has compromised the usefulness and importance of the concept. Even though it is clear that there is no agreement on the concept or the methodology that should be followed to assess it, it is generally acknowledged that social sustainability deals, to a greater or lesser extent, with social impacts.

Some variables that have been considered in the analysis of social impacts are health, safety, human rights and labour issues (Kruse et al., 2009, Mani et al., 2014, Popovic et al., 2018, Székely and Knirsch, 2005). In fact, more recent attention has even focused on the development of quantitative measures for the analysis of social impacts (Ahi and Searcy, 2015, Munier, 2005, Taticchi et al., 2015). Additionally, there exist a number of approaches to evaluate social sustainability: the standards developed by the Global Reporting Initiative (Global Reporting Initiative, 2015a,b) on the one hand and the Social Life Cycle Analysis (SLCA) (Andrews et al., 2009, Benoît-Norris, Catherine Traverso et al., 2013) on the other. The first approach is oriented to business processes and includes some topic-specific standards that are to be used to report information on the social impacts of organisations. Some of these topics are occupational health and safety, training and education, public policy and customer privacy. Conversely, the SLCA draws from the assessment methodology developed in the context of environmental sustainability. Other approaches account for social sustainability as an integrated part together with economic and environmental factors.

It should be mentioned that, in general, the studies that have evaluated impacts from a holistic perspective, including those related to the social pillar, are more often found in specific areas such as business or supply chain management (see, for example, Carter and Rogers, 2008, Hutchins and Sutherland, 2008a, Pagell and Wu, 2009, Seuring and Müller, 2008. Most of these studies fail to consider many fields whose social impact is also important. It is the case, for instance, of civil engineering (CE), in which researchers have mainly devoted efforts to the analysis of economic and environmental sustainability of infrastructures (Banihashemi et al., 2017, Kivilä et al., 2017, Martens and Carvalho, 2016) but have neglected social sustainability. Few exceptions do exist, such as Sierra et al. (2017), Montalbán-Domingo et al. (2018) and Sierra et al. (2018).

However, the effects that infrastructure services such as the supply of water and electricity, the disposal and treatment of wastewater or the mobility of people and goods have on society is huge, since they are drivers for socioeconomic development, competitiveness and inclusive growth (Calderón and Servén, 2014, Serebrisky, 2014). Infrastructures and the different stages existing from their initial planning until their decommissioning play a major role in sustainability, and in particular in social sustainability (Inter-American Development Bank, 2018). At the same time, society poses constraints on the design, planning, construction, maintenance, operation and decommissioning of civil works. This means that the relationship between society and infrastructures is bidirectional as each one can affect the other in different ways.

Even though there is evidence on the fact that the analysis of the impacts of CE must be carried out from an interdisciplinary point of view, until the present, engineering and social sciences and humanities have been set aside as separate scientific areas and research concerning the intersection between both of them has been very scarce. Decisions taken by engineers have, in very limited occasions, considered the participation or opinion of citizens and involved social groups, which are, actually, the ultimate users that would have to benefit from such decisions. The emergence of concepts such as socio-engineering indicates the growing relevance of connections between social and engineering/technological disciplines. Social studies of engineering have been showing the importance of understanding sociology when it comes to successful engineering. In the same way, technology and infrastructures are shaping the social world by enhancing, for instance, connectivity (both physical and digital) and comfort. As Bolton and Foxon (2015) point out, we need to understand better the interconnections between society and engineering in order to develop more sustainable and stable solutions.

It has to be born in mind that in many cases tools developed by engineers can be useful for the resolution of problems set out by sociologists, in the same way as approaches developed by professions of SSH can sometimes be applied in engineering fields. Besides, professionals are increasingly more aware of the indispensability of including citizen and social groups participation in the processes of decision-making, so that not only functional, economic and/or environmental factors are considered, but also social aspects.

Having said this, it is clear that interdisciplinary research on the analysis of the bidirectional relationship between SSH and CE is essential. In this context, the purpose of this chapter is to introduce the theoretical framework that guided all the research. This involves, first, the description of the state of interdisciplinarity in HE. Second, a conceptual framework that explains the relationships between civil engineering and social sciences and humanities is presented. This involves providind an overview of the social studies conducted in different areas of CE that allows proving the bidirectional relationship between the fields; and proposing a general framework that will guide the work carried out in the context of this thesis, and which can additionally be useful for both academicians and for practitioners.

3.2. Interdisciplinarity in higher education

The overarching framework within which this thesis lies is interdisciplinarity in HE. In this thesis, HE is understood as the primary knowledge creation system of society (Ison, 1999). Said system connects research with teaching and learning. Secondly, SSH are understood as the fields that study human behaviour and interactions in different contexts, such as social, cultural, environmental, economic and political. Evans et al. (2007) observe that "the humanities include subjects such as art, history and literature while social science includes subjects such as economics, political science, sociology and psychology." Thirdly, STEM is understood as Science, Technology, Engineering, and Mathematics. It has begun to be promoted in education to enhance the STEM workforce and address the major challenges at present (Bybee, 2010).

In this section, concepts and debates that are closely linked to this issue are presented. This includes discussions on the definition and benefits of interdisciplinarity and how this applies to the HE context. Interdisciplinarity in HE can have multiple facets, depending on whether it characterises research or teaching and learning. Hence, the case for interdisciplinarity when dealing with the intersection between SSH and Science, Technology, Engineering, and Mathematics (STEM) is reviewed first for research and then for teaching and learning. The specific case concerning SSH and CE is examined in the last subsection.

3.2.1. Interdisciplinarity in HE

There has been a growing number of studies on interdisciplinarity over the last decades. In the education context, Ashby and Exter (2019) see interdisciplinarity as the integration of knowledge drawn from diverse disciplines to address problems that cannot be solved by one discipline. In the literature, authors have classified interdisciplinarity into different degrees, ranging across intradisciplinarity, multidisciplinarity, crossdisciplinarity, and transdisciplinarity (Griffin, 2006). However, some authors have contested such division, arguing that interdisciplinarity is a further level in this classification (Jæger, 2018, Jensenius, 2012). The reader can find a review of the definitions and application of interdisciplinarity in the HE context in Chettiparamb (2007).

Given the central role of HE in interdisciplinary knowledge creation and dissemination, Power and Handley (2019) developed a best-practice model for integrating interdisciplinarity in HE. They grouped their results in four main areas, which are arguments given for the need for interdisciplinarity in HE, barriers, facilitators, and respective solutions.

First, regarding arguments, several authors centre the need for an interdisciplinary approach in HE around the fact that in today's world, most challenges are complex, and their solution requires a perspective that transcends traditional disciplinary borders (Ashby and Exter, 2019, Donina et al., 2017, Power and Handley, 2019, Van den Beemt et al., 2020). Stember (1991) suggested three arguments for interdisciplinarity: intellectual, practical and pedagogical.

Basu et al. (2017) highlighted the potential of interdisciplinarity for teaching knowledge and skills beyond students' disciplinary silos, developing an interest in other disciplines, integrating and examining problems from different perspectives, and learning to develop innovative solutions to complex problems. Besides, interdisciplinarity in teaching and learning can have significant benefits such as on graduate employability, problem-solving, communication or teamwork skills (Jones et al., 2010, Marcketti and Karpova, 2014, Newell, 1994, Nissani, 1997, Power and Handley, 2019). Leal Filho et al. (2021) reviewed the competences related to sustainability required by teaching staff and practitioners from literature, and their work shows how this is often linked to interdisciplinary thinking.

Secondly, barriers to interdisciplinarity in HE are identified by Power and Handley (2019) as a lack of resources, such as time or space, resistance to change from the staff, and the rigidity of regulations from academia and professional bodies. These issues are also reported by other authors, such as Bryant et al. (2014), Foster (1999), Jones et al. (2010), Nissani (1997).

Thirdly, some of the facilitators for integrating interdisciplinarity that Power and Handley (2019) detected in HE are incentives, staff mentality, new HE institutional structures, personal values, and physical proximity between disciplines in an HE institution. Other researchers also report these factors. For instance, Mullins (2007), Torrington et al. (2014) acknowledged individual recognition and effective talent management as key for interdisciplinary work in HE.

Finally, Power and Handley (2019) detect three interrelated solutions for better integration of interdisciplinarity in HE: better communication, an adequate structure and a cultural change. In fact, the need for a cultural shift in HE has been recognised by several authors (Annan-Diab and Molinari, 2017, Barlett, 2008, Kezar and Eckel, 2002). Lazzarini et al. (2018) emphasise the importance of the role of academics as agents of change. Even though they can lead to transformations, Lazzarini et al. (2018) argue that they could be more engaged in leading efforts to implement changes in HE programmes.

One specific area within the broad context of interdisciplinarity in HE is the intersection between SSH and STEM. This has led to interdisciplinary research and educational research. While the former is concerned with research projects with an interdisciplinary component, the latter is concerned with how best to introduce interdisciplinarity in teaching and learning. This is examined in the following two subsections.

3.2.2. Research

Okamura (2019) presented empirical evidence of the positive influence of interdisciplinarity on research performance by examining clusters of highly cited papers from different disciplines. Nonetheless, studies that look at the intersection between SSH and STEM from such a broad perspective are scarce. In general, researchers have analysed the relationships between SSH and a specific STEM field. Some of the areas that have been studied include climate (Kuster and Fox, 2017, Leyshon, 2014, Von Storch and Stehr, 1997), energy (Bavaresco et al., 2020, Mallaband et al., 2017), medicine (Smith and Grigsby, 2017, Timmermans and Tietbohl, 2018), and nanotechnology (Berube et al., 2020, Ebbesen, 2008, Zalewska-Kurek, 2016).

Some authors have examined the barriers that hinder interdisciplinary research between SSH and STEM. Schuitema and D. Sintov (2017) identified challenges and obstacles for interdisciplinary research in the context of SSH and energy. According to their results, these barriers are insufficient knowledge and skills, limited and unequal distribution of funding, funding evaluation criteria, publication processes and academic promotion processes favouring disciplinary research, and a lack of HE institutional systems for interdisciplinarity. Apart from these issues, Rekers and Hansen (2015) examined these barriers from a geographical perspective which, they argue, adds to other barriers for facilitation of interdisciplinary research.

3.2.3. Teaching and learning

Research regarding teaching and learning in HE at the intersection between SSH and STEM can frequently be found in the context of sustainability, in what is referred to as Education for Sustainable Development (ESD). Some of the studies developed so far focus on sustainability integration in STEM programmes (Feinstein and Kirchgasler, 2015, Zizka et al., 2021). Because of the nature of sustainability issues, this usually implicitly encompasses interdisciplinarity. As Newell (1994), Spelt et al. (2017) put it, SSH are embedded in the context of interdisciplinary thinking. For instance, Leal Filho et al. (2021) regarded social responsibility, ethics, and cultural diversity as essential competencies for staff teaching sustainability, and Corrêa et al. (2020) highlighted the importance of including social sustainability elements in undergraduate programmes.

Several authors have reported academic experiences of sustainability or SSH integration within STEM courses. Tasdemir and Gazo (2020) analysed how sustainability could be integrated into a specific course within a STEM department. Hergert et al. (2010) reported an academic project in which groups of students from a range of degrees, both SSH and STEM, had to prepare presentations for an interdisciplinary audience.

Besides curricular activities, Lattuca et al. (2017) performed a survey among STEM academia regarding perceptions concerning interdisciplinarity, which also included questions on SSH. They found the importance of curricular activities on students' perceptions of interdisciplinarity and the potential of extra-academic activities to develop social skills. In a similar vein, Spelt et al. (2017) surveyed STEM students about their experiences related to the cognitive, emotional and social learning dimensions in HE.

Specific studies on HE curricula dealing with the inclusion of SSH in STEM programmes are scarcer. For instance, Molthan-Hill et al. (2019) examine climate change education and propose a conceptual framework on how HE institutions can deploy said integration in practice. They detected four different ways in which this can be done: specialist approach, piggybacking, mainstreaming, and connecting. In Sochacka et al. (2016), the introduction of Arts in STEM education is seen as a means of enhancing students' creativity. They coined a recent term, STEAM, which adds an A for Arts and Humanities to the original STEM acronym. There are multiple advocates for such an approach (de la Garza, 2019). The TEACHENER project (Stankiewicz, 2019) had the main purpose of enriching energy courses through teaching social sciences, and it supported the development of teaching modules covering topics related to social aspects of energy for educating graduate students. Some of the modules that they included were philosophy and ethics of energy development, the social impact of energy technologies, and conflict management.

3.3. The "social" in civil engineering

Having discussed the general framework of this thesis, interdisciplinarity, it is important to understand what is the state-of-art in terms of integration of social sciences and humanities in civil engineering. This is why the following subsections describe the reviewed publications in the intersection between social sciences and humanities and civil engineering.

The number of publications identified in the first stage of the literature review performed to build the framework is shown in Figure 3.1. In this figure, a total of 12 heatmap diagrams can be used to identify what combinations of keywords resulted in the greatest amount of publications[1]. Each diagram's colour depends on the number of publications found for a specific social science keyword (horizontal axis) and a specific field of CE (vertical axis).

[1]The keywords that were used were presented in Section 2.2.1.

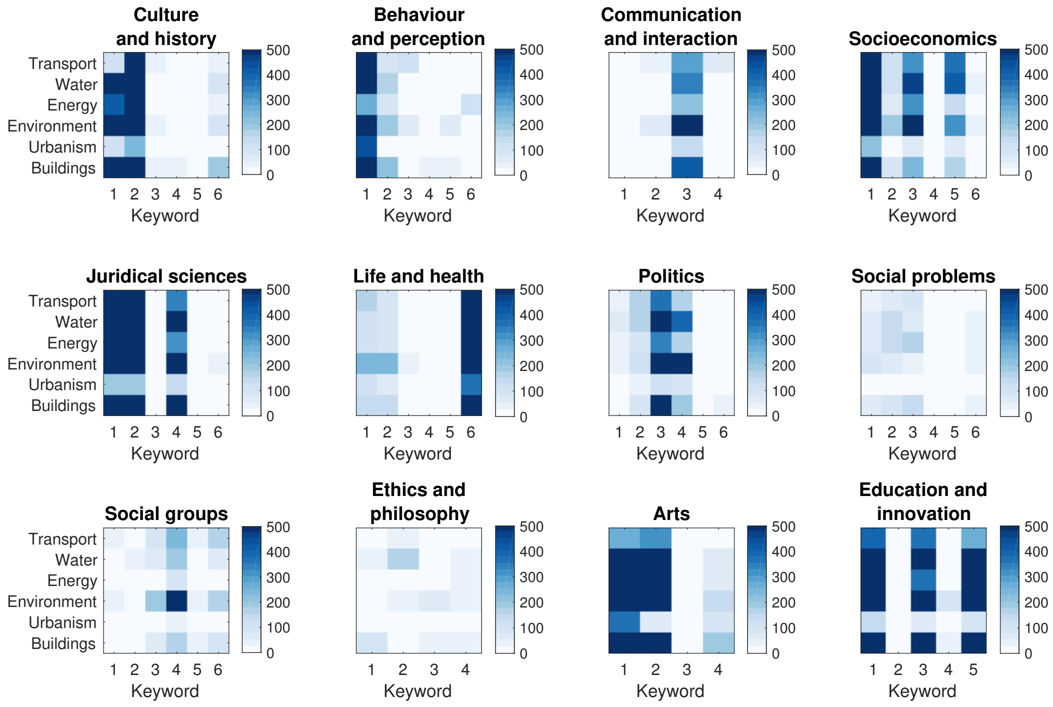

Figure 3.1. Number of publications found in the first database search

Figure 3.2 presents the distribution of all the papers across time. It shows how the number of publications dealing with topics both from CE and SSH increased very quickly after the 80s. Besides, Figure 3.3 shows a colourmap that has been drawn based on the number of publications reviewed for each subfield.

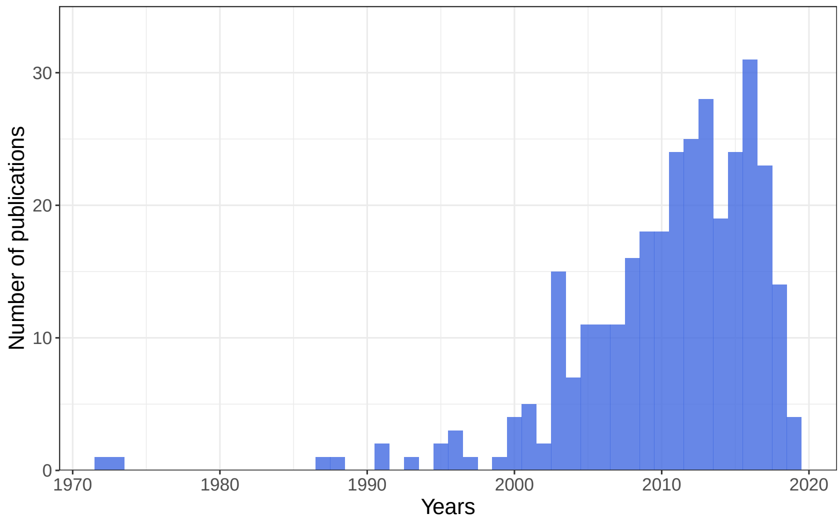

Figure 3.2. Distribution of publications reviewed per year

Having said this, in the following sections, a synthesis of the reviewed publications is presented. The findings are described grouped according to their corresponding civil engineering, namely transport, water technology, energy technology, environment technology, urban planning, and buildings.

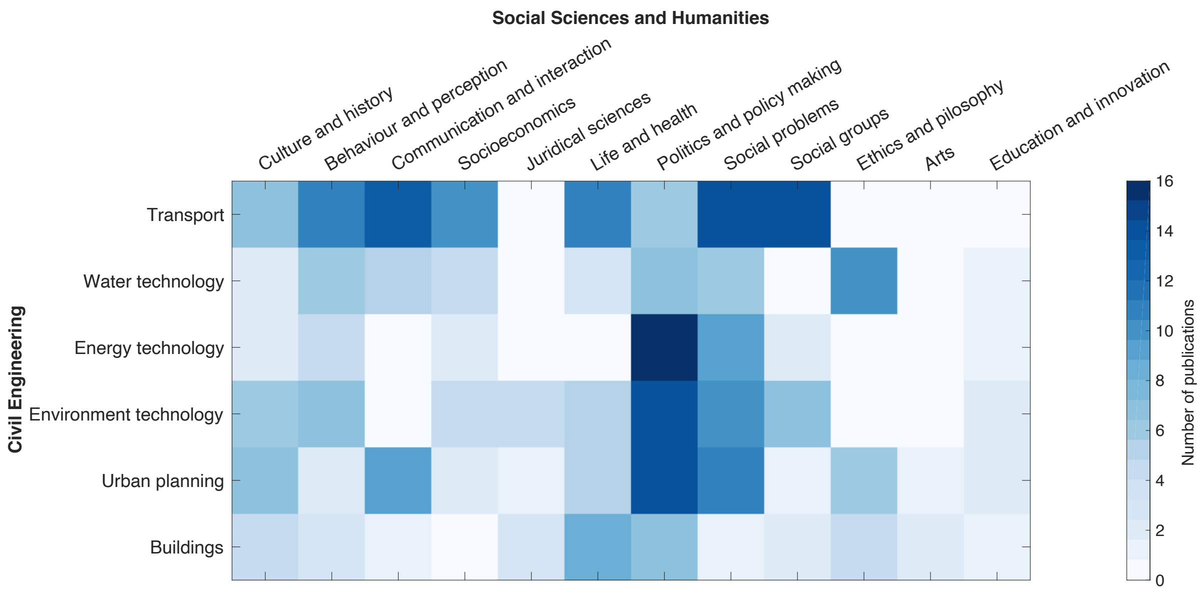

Figure 3.3. Number of publications that correspond to the different intersections between civil engineering and the social sciences and humanities

3.3.1. Transport

Transport services and mobility infrastructures have always played an important role in the development of society (Ghimire, 2017), originally through land- and maritime-based routes, but more recently also through air-based ones. Civil engineers working in transportation systems are responsible for the provision of safe, efficient and convenient movements of both people and goods.

The social study of transportation systems has given rise to a high amount of literature. For instance, Sheller and Urry (2006) describe how the development of both transportation infrastructure and modes has had a huge impact on the SSH and has transformed the relationship between travel and connections with social patterns and experiences. The cross-disciplinary research agenda drawn from these new relationships has been referred to as the “new mobilities” paradigm or the “mobility turn”; contributions to these paradigm changes come from several fields such as anthropology (Verstraete and Cresswell, 2016), culture (Appadurai and Arjun, 1996, Hetherington and Degen, 2001), politics (Shiftan et al., 2003) or geography and migration studies (Kaufmann et al., 2004, Ralph and Staeheli, 2011). Actually, there exists in the SSH a research area referred to as sociology of mobilities and space, whose study focus are the social aspects of movement. Although traditionally the study of mobility from a sociological standpoint has been that of vertical mobilities (Vannini, 2010), or also called the social elevator, the mobility seen as a more material concept has been laid aside. Namely, mobility linked to the geographic movement of people for work and leisure or due to the need for migration within or between countries, for instance. Besides, some authors have argued that transportation is not merely the instrumental or neural tool for getting from A to B (Vannini, 2010), but also an element that shapes relationships and interactions between people (Dugundji et al., 2011, Pucci and Colleoni, 2016), networks of time and space (Cresswell, 2006, Grieco and McQuaid, 2012, Pathak et al., 2017) and provides meaningful different significances to experiences (Cresswell, 2006).

The social approach to transport and mobility can be classified into a micro lens and a macro lens. The former approaches the relationship between SSH and transport by focusing on the individuals and firms regarding the use and provision of transport. The latter takes on a broader perspective by dealing with all the interactions caused by the transport network as a whole and at any level (local, national or international).

On the one hand, at the micro level, Jones and Lucas (2012) performed an extensive review on the social impact of transport and found that the main areas in which transport has influence are accessibility, movement and activities, health, finance and community relations. Church et al. (2000) classified this micro lens into two different categories: a category approach and a spatial approach. The former is concerned with factors related to transport demand (such as travel patterns, attitudes, needs, etc.) whereas the second approach comprehends aspects of transport supply like quality of transport, access (either to public or private transport) or spatial gaps.

Within the category focus, the analysis of the demand and its relationship with human characteristics is a field that has been given great importance. Many authors have been able to identify divergences in the usage of transportation which are usually directly correlated with differences in factors such as life course stage (McLaren, 2016, Sun et al., 2009, Waygood et al., 2015), gender (Ghani et al., 2016, Grieco and McQuaid, 2012), age (Collia et al., 2003, Ghani et al., 2016, Hjorthol et al., 2010, Horner et al., 2015), culture or geography (van den Berg et al., 2017) and attitudes and behaviour patterns (Hackney and Marchal, 2011). All these factors are, additionally, affected by individual subjectivities such as personality traits, attitudes and feelings (Bergantino et al., 2013, Heinen, 2016, Murtagh et al., 2012, Yazdanpanah and Hosseinlou, 2016). These differences are not only in modal choice (transit, walking, cycling, carpools, etc.) but also in other aspects such as trip distances or purposes (Boschmann and Brady, 2013). Additionally, apart from individual characteristics affecting demand, another aspect that has been studied is the effect of information provision on users (Emmerink et al., 1995). As Hackney and Marchal (2011) point out, all these factors do not appear independently at an individual level: there are interrelations between the transportation use that different people make.

Another central topic in mobility research is its intimate connection with well-being and quality of life (Delbosc, 2012, Doi et al., 2008, Spinney et al., 2009). Factors such as participation in activities outside of home, in social and community life or the communication and interaction with other individuals are directly related to social and emotional well-being (Boniface et al., 2015, Mollenkopf et al., 2005, Schaie, 2003, van den Berg et al., 2017, Vella-Brodrick and Stanley, 2013). Particularly, in this research field many authors have analysed the specific case of the elderly's accessibility and mobility (Johnson et al., 2017, Musselwhite et al., 2015, O'Hern et al., 2015, Shergold et al., 2015); however, other studies have focused on other age groups such as teenagers (Ward et al., 2015). Webber et al. (2010) present a holistic framework that incorporates all the variables influencing the mobility of the elderly, such as their living situation and functional ability. Their framework includes different physical locations as well as five mobility determinants (financial, psychosocial, physical, environmental, and financial) that are influenced by gender, cultural and biographical characteristics. Spinney et al. (2009) emphasise the need for developing transport systems that account for their impacts on social exclusion and quality of life. In their work, they present an enhanced method to evaluate and critically understand the impact that transport mobility has on quality of life.

A particular case that has gained much attention is that in which these differences are occasioned on vulnerable groups or commonly excluded population. Actually, in the social studies of transportation, equity and social inclusion are some of the topics that have been more widely discussed (Currie et al., 2007, Delbosc, 2012, Geurs et al., 2009, Lucas, 2004). The vulnerable groups may be constituted by children, women, older people, disabled people etc. (Wasfi et al., 2017). As some authors point out, incorporating policies dealing with transport-related inequalities into policies other targeting social inclusion objectives (such as residence or employment) can bring about better results on these objectives (Litman, 2002, Xia et al., 2016). The issue of social exclusion linked to transport relates to the concept of the right to mobility and of transport justice; this concept advocates for equal distributions of the benefits and burdens of urban transport (Gössling, 2016, Verlinghieri and Venturini, 2017). Gössling (2016) identifies three areas in which transport injustices occur: exposure to traffic dangers and contaminants (Gaffron, 2012), distribution of space and the value given to the time of transportation.

In order to be able to target problems stemming from social injustices in transportation, Hananel and Berechman (2016) built a decision-making framework based on Sen and Nussbaum capabilities approach (Nussbaum, 2005). To this purpose, they analised the relationships existing between the different human capabilities and transportation theories. A difficulty encountered in this analytical methodology lies in the complexity of defining a valid threshold for real-life approaches to transportation. Other capability approaches to transportation that have been developed can be found in van Wee (2012) and Wismadi et al. (2014).

As civil engineers, the different processes involved in transport infrastructures are carried out so that they are developed safely, efficiently and conveniently. Most frequently, the purely engineering side of transportation (such as construction requirements or service levels) conflicts with its societal side (Hananel and Berechman, 2016). The main issues involved in this dissension are (1) the technical problems involved in the identification of disadvantaged populations and individuals; (2) the fact that, in general, transportation models are based on the average trip-maker or resident and therefore the planning measures and design are carried out accordingly; (3) economic and political feasibility.

On the other hand, moving to its analysis from a macro perspective, transport has been seen as a catalyser of economy for various reasons: an improvement in the efficiency of transport systems can generate productivity gains and therefore, produce an economic impact; at the same time, enhancing people and industry's access to certain resources, services and markets can also improve productivity. Other noticed impacts are the support of clusters and agglomerations, the enhancement of access to jobs and labour market and the opening or enlargement of markets for businesses (Arbués et al., 2015, Holl, 2016, Jiwattanakulpaisarn et al., 2010, Litman, 2017, Meersman and Nazemzadeh, 2017). Not only does transport infrastructure impact the region in which it is located, but it has the potential to reach nearby regions through what is known as the spillover effects (Holtz-Eakin and Schwartz, 1995, Jiwattanakulpaisarn et al., 2010, Yu et al., 2013). Apart from considering the economic effects that transportation systems have on society, transport engineers must also take into account other conditions that might restrict their design and planning processes, as well as affect their performance in the long-term: geographic constraints and political interests (Carpintero and Siemiatycki, 2016).

3.3.2. Water technology

Water is essential for life and human beings need a minimum amount of water to survive; therefore, infrastructure providing water is fundamental (Koo and Ariaratnam, 2008). This importance was acknowledged long ago; the right to water and sanitation services was included in the list of universal human rights by the United Nations (United Nations Development Programme, 2010), and Lorrain and Poupeau (2014) referred to water supply services as an essential piece within human settlements due to their socio-technical nature. The impact that water technology has on societies is huge; apart from the benefits obtained from it such as covering the basic physiological needs and other dimensions of human well-being, it can also have serious consequences such as the dislocation of whole communities (Nüsser, 2003). Brauman et al. (2007) proposed connections between different hydrologic systems and human well-being; the dimensions that they considered were basic needs, physical and emotional health, social interactions, security and freedom.

Water provision is multidimensionally affected by technical, economic, environmental, social and political factors. Even though traditionally the management of water resources has been mainly based on technical solutions and its infrastructure planning processes have been highly influenced by engineers and local authorities, this is starting to shift towards a more society-oriented focus. This means for instance to involve SSH research (Lienert et al., 2013), to allow for governance and cultural adaptation, to adapt to new challenges such as changing socio-economic conditions and uncertainties due to climate change (Pahl-Wostl et al., 2007) or to involve the values of individuals and stakeholders in the decisions concerning water management (Lennox et al., 2011).

Actually, water infrastructure planning processes involve a complex network of stakeholders. At the same time, infrastructures themselves, such as of water supply or watershed affect numerous actors (Ison et al., 2007). Lienert et al. (2013) group the stakeholders that play a role in water infrastructure planning according to the level in which they make the decisions: local, cantonal or national. Within the local level, actors such as local engineers, planning consultants, suppliers, municipal administration and politicians and manufacturers can be found; within the cantonal one, cantonal agencies, offices and councils; within the national one, country associations, federal offices or NGOs.

As pointed out by Lennox et al. (2011), the engagement of stakeholders in decision-making is of importance in the governance of water resources. Examples of studies of social participation methods and case studies can be found in Hartley (2006), Ison et al. (2007) and Pahl-Wostl et al. (2007).

The term governance used as a core theme in the global water discourse rose around the beginning of the 21st century (Mollinga, 2008) and this allowed for the consideration of more aspects apart from the operation of water infrastructures itself, such as interest groups or social participation. This term embraced a more inclusive concept in contraposition to words such as government or management. As Rogers et al. (2003) introduce, governance encompasses the connection society-government since it is the collection of systems, political, social, economic and administrative, whose aim is the regulation and development of water resources management and provisions of water services at different levels of society. Some key aspects of good water governance are ethicality in the decision-making processes, impartiality by the decision-maker and inclusion of all the relevant actors (Lukasiewicz et al., 2013a,b, Neal et al., 2014, Syme et al., 2015).

Water-related problems have frequently been related to problems of justice and therefore governance of hydrologic systems needs to consider the justice implications of their activities. The fair distribution of water access and political water decision-making has attracted attention since it affects the water rights and water-based livelihoods of many communities around the world (Zwarteveen and Boelens, 2014) and has caused conflicts and social movements (Davidson-Harden et al., 2007, Neal et al., 2014). Further studies on water distribution and water injustices can be found in Budds (2004), Loftus (2009), Ahlers (2010) and Perreault et al. (2012) and on the centralisation of water resources in Gandy (2003) and Swyngedouw and Heynen (2003). These issues have often led to spatial inequalities (Harvey, 1973, Kudva, 2009, Nilsson, 2006). Related to these are the existing gaps and unequal distribution of the supply of water and sanitation services. In metropolitan areas, for example, water scarcity is becoming a problem due to the gap between the rapidly increasing demand and the infrastructures supply capacity (Britto et al., 2018), infrastructures that are poorly maintained and irregularities in the supply. For an extensive review of contributions related to water justice, the reader is referred to Neal et al. (2014).

In the design of hydrologic systems, an additional social aspect that needs to be included is human behaviour and attitudes towards water use and demand; this is not the result of a single variable but of a variety of different factors such as household size, income or available infrastructure (Ahmadvand et al., 2011, Sofoulis, 2005). This fact leads to differences in water consumption among different social groups. Additionally, there are other external factors that also influence this behaviour, such as social pressures or the influence of different lifestyles (Kitamura et al., 1997). There have been alternative studies concerning water consumption behaviour, in this case in how individuals conserve this asset (Lehman and Geller, 2004, Thompson and Stoutemyer, 1991, van Vugt, 2001, Wolfe, 2009). Also, how communication concerning water-related issues is carried out might influence these attitudes towards it (Johnson, 2008).

3.3.3. Energy technology

Energy has historically had a crucial role in social development. Even though energy systems have traditionally been seen as technological and economic phenomena, they are actually strongly connected to several social, political and organisational factors (Miller et al., 2015). This emphasises the importance of analysing energy from a social point of view. Actually, according to Strauss et al. (2013), the challenges that power technologies currently face are social rather than technological; along this line, Hornborg (2013) specifies the multiple perspectives that energy takes: historical, sociological, economical, ecological, cultural, epistemological, etc.

The social studies on energy in the literature mainly focus on three different areas: its political, ethical and socioeconomic implications (which are mainly related to energy governance and justice), the factors that influence the use and demand of energy and the attitudes towards and perceptions of energy.

Access to energy is one of the sustainable development goals and it advocates for energy services that are affordable, reliable and modern for all population. Therefore, energy policies and priorities need to change together with this paradigm shift. At the core of the change needed lies energy governance, understood as the way in which actors establish and enforce rules to address energy-related problems has extensively been treated in the literature. Many researchers have presented the challenges related to effective governance existing such as unclear levels of resilience and authority, weak resilience, inadequate prioritisation of investments or political conflicts (Bolton and Foxon, 2015, Goldthau and Sovacool, 2012, Langlois-Bertrand et al., 2015, orn Poocharoen and Sovacool, 2012, Sequeira and Santos, 2018, Stokes, 2013), as well as described governing arrangements and norms that would allow to approach these challenges (Delina, 2012). Besides, energy governance has been considered at different political levels and even though it has mainly been looked only at local or regional (Parag et al., 2013, Peters et al., 2010) and national levels (Sovacool and Mukherjee, 2011), some authors have advocated adopting a global perspective on energy governance since, they argue, energy is a global public good (Benner et al., 2010, Bruce, 2013, Gururaja, 2003, Karlsson-Vinkhuyzen et al., 2012). International energy markets have often been seen as lacking appropriate governance due to the ineffectiveness of governments and non-State actors in global coordination and regulation of energy services (Florini and Sovacool, 2009). According to Fontaine (2011), energy governance usually follows two different patterns: a hierarchical one, which is centralised and state-centred; and a cooperative one, which is more decentralised and market-oriented. Following this line, Goldthau and Sovacool (2012), Williams (2010) study the (de)centralisation of energy.

Giving a perspective that focuses more on the energy infrastructure itself rather than on the necessary political structure, Bolton and Foxon (2015) describe the collection of governance challenges that can be encountered during the different stages of the lifecycle of infrastructures. They also analyse the importance that certain actors play, such as government, private network operators, local authorities and energy regulators. Along with this line, Parag et al. (2013) specifically assess the incorporation of certain actors in energy governance networks.

Apart from energy governance, another concept that is frequently mentioned in social analyses of energy is energy justice. This refers to the global energy system that distributes in a fair way the benefits and burdens of energy services and that contributes to more representative and inclusive energy decision-making (Sovacool et al., 2017). Regarding energy justice, two main issues arise: energy poverty and energy inequalities.

Firstly, as for energy poverty (also referred to as fuel poverty, domestic energy deprivation or energy precariousness), there is not yet a common agreement on its definition. Some have defined it as a household's lack of access to socially and materially needed levels of energy services (Bouzarovski, 2014), while others have referred to it as the lack of access to affordable and high-quality energy services (Bazilian et al., 2014). In spite of the differences in definition, what has been made clear is that energy poverty is a multidimensional problem shaped by several different circumstances apart from its technical performance. Some important drivers of energy poverty are the socio-economic situation of the household, the efficiency of the energy system of the dwelling and energy prices (Boardman, 2013, Meyer et al., 2018). At the same time, vulnerability to energy poverty is dependent on different factors, both at a household level such as income, age, or dwelling typology (Bouzarovski and Simcock, 2017) or at external levels such as the high cost of energy. The measurement of energy poverty has faced various challenges for diverse reasons such as that energy is a private service, that it is spatially and temporally dynamic or that its quantitative evaluation might be subjective. Accordingly, the methodologies proposed differ widely. Some of them are the expenditure-based measurement, which uses the 10% rule (Boardman, 1991), the Minimum Income Standard approach (MIS) (**?**) or the Low Income High Cost (LIHC) indicator (Hills, 2011).

Secondly, studies on energy inequality can be found in references such as Bouzarovski and Simcock (2017), Yenneti et al. (2016). As pointed out in their paper, the amount of research performed on this topic is still scarce and it actually focuses on commonly studied groups such as elderly people and people living in rural regions; urban dwellers and collectives such as immigrants and tenants have not received as much attention (Bouzarovski, 2014).

In the design of energy systems, prediction of energy demand is essential. Therefore, it has to be considered in the design and construction stages of energy infrastructure. Factors influencing energy consumption are not only technical but also related to the context. As pointed out by Zhao and Magoulès (2012), these factors include: climatic conditions, characteristics related to the building such as its area or orientation, characteristics related to the user, building services systems and operation, behaviour and activities of the users, social and economic factors such as level of education and energy cost and the indoor environmental quality required. The papers in the literature that are related to the modelling of energy consumption behaviour are numerous (Allcott, 2011, Yu et al., 2011).

According to many authors, how energy is developed, used and contested is shaped by how individuals and collectives conceive it. For instance, Strauss et al. (2013) describe the bidirectional relationship between cultural concepts and beliefs with energy: how individuals perceive energy transforms how they make use of it; at the same time, different uses of energy also modify individuals' beliefs about energy.

3.3.4. Environment technology

Environmental quality has a strong influence on the quality of life of human beings (Banzhaf et al., 2014, Domínguez-Gómez, 2016). Besides, the roles that civil engineers play within environment technology, which are related to the connection between human action and engineering principles and environment, are fundamental. They undertake the task of protecting humans from the effects of environmental actions and the enhancement of environmental quality. Mainly, they work on recycling, water pollution, air pollution and solid waste management (SWM) and resource recovery systems. Even though SWM has been considered by some as one of the most important challenges for a sustainable design of cities (Guerrero et al., 2013, Sharholy et al., 2008, Shekdar, 2009, Zaman and Lehmann, 2011), systems for SWM have not received as much attention as sectors such as the water or energy ones. Due to the rapid increase in the number of city dwellers around the world, there has been an acceleration of solid waste generation rates. In this context, engineers need to provide inhabitants with SWM systems which are both effective and efficient.

The social dimensions that need to be considered when designing such a system are multiple. Actually, some authors have advocated for integrated systems (Integrated sustainable solid waste management systems) in order to be able to encompass all the complexities and multidimensionality of these systems (Guerrero et al., 2013, Marshall and Farahbakhsh, 2013, Pahl-Wostl et al., 2007, Shekdar, 2009). The performance of these environmental technology systems depends strongly on human attitudes and collective behaviours. Also, socioeconomic, demographic and cultural factors have been pointed out as critical when it comes to understanding the barriers to the adoption of these technologies and new management strategies. Such factors include, among others, age, gender, income, education, family size, residence type, location, cultural beliefs and the historical context (Bandara et al., 2007, Gallego-Álvarez and Ortas, 2017, Kopnina, 2017, Ma and Hipel, 2016, Marshall and Farahbakhsh, 2013, Pahl-Wostl et al., 2007). The wide variety of variables on which the performance of environmental systems depends emphasises the need for adapting these systems to the socioeconomic, demographic and cultural contexts. Also, policies and decision-making processes on environmental technologies need also to consider the huge effect that these infrastructures have on people's health and quality of life (Pacione, 2003, van Kamp et al., 2003).

Governance also plays an important role in these processes. For instance, it can help to integrate effective user participation or feedback learning (Berkes, 2010). Therefore, good governance should aim at incorporating the numerous stakeholders involved and interested in waste management: national and local governments, municipal authorities, city corporations, non-governmental organisations, households, private contractors, ministries, recycling companies, etc. (Joseph, 2006, Lederer et al., 2015, Srivastava et al., 2005, Yedla, 2012). Yedla (2012) suggests that stakeholders join into partnerships, which not only would bring economic benefits but also systemic ones. Policies concerning the involvement of these stakeholders in the process of waste management and the various stages of SWM have been developed (Ma and Hipel, 2016, Taylor, 2000). These policies include laws and regulations such as bans, control standards or product specifications (Moh and Abd Manaf, 2017, Vassanadumrongdee and Kittipongvises, 2018, Zhang et al., 2010); they also involve incentives that are socio-psychological or economic such as public subsidies, user charges or product charges (Chen et al., 2010, Lohri et al., 2014, Troschinetz and Mihelcic, 2009).

According to Awuorh-Hayangah and Oladapo (2015), good governance and sustainability in environmental management are intimately linked to justice, corruption-free, non-partisan and stable political systems. Among these, justice, and more specifically distributive justice, is a central theme (Chaix et al., 2006, Fan, 2006, Higginbotham et al., 2010, Hillman, 2006, Kubanza and Simatele, 2016, Myers, 2008, Patel, 2009, Pearce et al., 2006, Walker, 2012). In particular, there exists an ongoing discussion about the low social status that is associated to one of these stakeholders, waste workers, as well as about the existence of an informal sector that has emerged from solid waste. This informal sector is made up of unregistered, unregulated individuals, groups or small businesses that benefit from waste (Nzeadibe et al., 2015). These individuals are potentially under labour intensive situations and working at low income rates. The existence of this informal sector is directly related to socio-economic conditions, to policies related to urban environmental management and to the physical characteristics of urban regions. All these factors increase the availability of waste for the informal sector (Sembiring and Nitivattananon, 2010). In some countries, the amount of people working a living from waste is large, which brings about more poverty and marginalisation (Berthier, 2003).

However, vulnerabilities are not only related to informal sector workers. In all the stages of solid waste treatment (collection, transport, storage, classification, clearance, sell, reuse) environmental contamination may cause a differential impact on the exposed populations in terms of health, income and access to services. The same happens with air and water pollutants. This impact is potentially greater on vulnerable groups or communities such as children, women, elderly people, poor people or minorities (Candela et al., 2013, Giovannini et al., 2014, Levy and Patz, 2015, Makri and Stilianakis, 2008, Nunn and Gutberlet, 2013).

Finally, apart from environmental justice, some authors have also considered the importance of resilience and adaptability in the discourse of governance of environmental systems (Popke et al., 2016, Sandoval et al., 2014).

3.3.5. Urban planning

Urban planning is the discipline that is in charge of several aspects of the planning, design and development of land use and built environments of municipalities and communities. It is a field that was traditionally formalised by architects and civil engineers; however, since the last decades this has changed and urban planning has permeated into other areas such as economic development or environment. According to Schmidt (2008) and Schmidt and Németh (2010), public space is not only a physical space but also a dynamic construct created by society that is influenced by politics, culture and factors related to public health. This shows how the connections between the tasks that urban planners perform are strongly linked to those of social scientists. Actually, Pickett et al. (2004) recognize cities as a whole, both ecologically and socially, and advocate for forming teams of interdisciplinary professionals who can provide better designs by creating urban models that are socially and ecologically sensitive. Besides, urban spaces are continually evolving, their form and functions adapting to the different social, political and economic circumstances. Recent political and economic transformations, such as globalisation, increased mobility and the boost of telecommunications technology have brought with them changes in the ways cities and public space are produced (Logan and Molotch, 1987, Schmidt and Németh, 2010).

As for the concept of public space per se, it is not easy to find a unique definition. The way public space is perceived depends on anthropological and cultural dimensions such as class origins or ethnicity and there can actually be big differences between the perceptions of planners and users (Oliver-Smith and Goldman 1988). Jamalinezhad et al. (2012), for instance, recognise the effect of culture as central in urban planning, apart from political, economic and social factors (Jamalinezhad et al., 2012). This is, in part, due to the fact that built human settlements (such as cities or residential area compounds) comprise important tangible manifestations of human culture. Examples of studies focused on the way urban development and form change according to cultural factors can be found in Larson (2003) and Chadha and Onkar (2016). Blessi et al. (2016) provide a description of the role of culture in contemporary urban life. As pointed out by the author, culture can have substantial impacts on urban areas by providing them with meaningful symbolic, competitive, environmental, economic and social value. Additionally, urban forms contribute to the aesthetics of the public space (Garrett, 2016).

There are many papers in the literature that are related to how different forms of urbanism can have several different effects on individual's and communities' health and quality of life. There is a strong connection between various urban features and physical and mental health (de Hollander and Staatsen, 2003, Díez et al., 2016, Dong and Qin, 2017), or quality of life and human wellbeing in general (Khalil, 2012, Pacione, 2003). Of these features that influence individual wellbeing, the following ones can be emphasised: green spaces, urban density (Guite et al., 2006), commuting (Stutzer and Frey, 2004) and housing (**?**). Furthermore, physical environment not only has an individual impact, such as on human well-being, but it also has collective effects on communities: it affects the way people behave and interact (Glanz et al., 2016, Shin, 2009). Urban forms create opportunities for social interactions (Farida, 2013, Huang, 2006, Leikkilä et al., 2013, Shin, 2009) or can even control or create barriers through, for example, urban planning laws and regulations, which arrange the social relations between and within social groups by regulating the places for social gatherings (Shin, 2009).

Urban governance, planning for resilience and urban justice are three topics that have widely been discussed in the literature. Currently, the models of urban governance around the world are numerous, since its organisation depend on local and national contexts that are intimately linked to general norms, values and practices (Pierre, 2011). da Cruz et al. (2019) carry out an extensive review on currently discussed challenges among academic publications. Their results show that the five topics that attract more attention are citizen participation, institutional shortcomings, government capability, civil society organisation engagement with decision making and vertical coordination between government tiers. However, they argue that there is a disconnection between what academics are concerned with and the reality in cities around the world. Through a survey, they present the challenges that are currently being faced by cities; the first five ones are insufficient public budgets, the politicisation of local issues, the interdependence of policy issues, inflexibility in the bureaucratic procedures and rigidity of rules, and lack of municipal autonomy. Some challenges that have been identified in relation to urban governance and resilience are globalisation, climate change, migration and security (Brenner, 1999, da Cruz et al., 2019, Evans et al., 2007, Pelling, 2010).

Finally, urban justice is generally understood as the right to a safe living environment and access to urban resources. Examples of studies on theories of justice related to urbanism can be found in Attoh (2011), Fraser (2009), Nygren (2013), Schlosberg (2013), Walker (2012), Wayessa and Nygren (2016). Aspects that need to be accounted for in urban planning are accessibility (De Montis and Reggiani, 2013). From a more practical standpoint, the right to the city has been studied in de Vries (2016), Merrifield (2014). Nygren (2018) deals with both justice and governance problems. Tonkiss (2013) also points out that planning and designing urban environments is a “social process”. As pointed out by Harvey (2003), city justice is not only related to having access to urban resources, but also to being able to participate in the changes to which cities are subject; this shows how, for some, participation needs to play a central role in urban planning. Participation, which is disjunctively seen as involving people in the making and implementation of policies and as including people in government structures, has been dealt in relation with urban planning by several authors (Hassan et al., 2011, Wissen Hayek et al., 2016). Accounting for citizens in the design process of urban landscapes is important to promote community support and to bring about better urban configurations (Matsuoka and Kaplan, 2008). Another benefit of increasing participation is, as Hassan et al. (2011) point out, the prevention of social exclusion. If practitioners don’t consider the characteristics and needs of all citizens, benefits and burdens among human populations might be socio-spatially distributed; this means that it is possible that some people and places are devalued in comparison to others (Nygren, 2018). For example, Gerometta et al. (2005) present a case in which city dwellers suffer most from social exclusion and urban policies potentially result in institutions that are more exclusionary. Other studies of inequality related to urban planning can be found in Barbosa et al. (2007), Dai (2011), Manley (1996), Shanahan et al. (2014).

3.3.6. Buildings

The spectrum of social topics concerning buildings is wide. In this review, we have identified four main areas related to this field: social housing, health and comfort, social perception of liveable spaces and construction management.

First of all, social housing, whose aim is to provide liveable spaces that are more affordable, has been considered key in social policies (Bramley, 2007); some analyses of its plan, design and impact on users can be found in Kowaltowski and Granja (2011), McManus et al. (2010), Morano and Tajani (2017), Salzer et al. (2016), Sdei et al. (2015), Sunikka-Blank et al. (2012), Yao (2012), which mainly approach the improvement of energy efficiency and sustainability of this kind of buildings.

Secondly, many publications deal with the impact on people’s health of buildings and comfort from different perspectives. As for health and quality of life, research has mainly focused on liveable conditions for the elderly (Leung et al. 2016, 2017). As for comfort, this entails aspects such as temperature (D’Ambrosio Alfano et al., 2014), perception of vibration (Kwok et al., 2009), acoustics (**?**), olfaction and aesthetics (D'Ambrosio Alfano et al., 2014, Veitch, 2001). Some authors have referred to this collection of factors as indoor environmental quality (IEQ). In relation to social housing, some authors have analysed how sometimes residents of these buildings are more prone to reporting discomfort (Vakalis et al., 2019).

Thirdly, how housing and buildings in general are perceived by their users and society is described in the literature. These publications deal with diverse aspects such as social response to construction delays, perception of risk (Khew et al., 2015) and the way buildings change how places are experienced (Hadi et al., 2018).

Fourthly, construction management is the service that provides the techniques to manage the different stages in the life cycle of an infrastructure (planning, design, building, operation, maintenance and decommission); therefore, of the factors that have been mentioned in this study dealing with the different CE subfields are implicitly embodied in the process of construction managing. Here we focus on publications dealing with the inclusion of social aspects in construction projects in general terms/itself. The great majority of reviewed papers dealt with the incorporation of social elements as part of the process of considering sustainability in construction projects. Many authors have emphasized the lack of integration between social issues and construction project management (Choguill, 1996, Marcelino-Sádaba et al., 2015). Some of the barriers to better social assimilation in projects are the complexity of the systems (Ravetz, 2000), the lack of social awareness (Tan et al., 2011), lack of support from project stakeholders (Morrissey et al., 2012) or laws and regulations. As for this last impediment, even though there exist laws and regulations that are socially beneficial, they can sometimes be detrimental for society (Zhang and Dong, 2011, Zhang et al., 2012). As pointed out in Morrissey et al. (2012), early intervening in infrastructure projects to account for social aspects is potentially more effective and efficient when it comes both to economic and social terms; to support their viewpoint, they propose a framework for the development of infrastructure at different strategic levels. Corporate Social Responsibility has also been highlighted by some authors in order to induce ethical behaviours which could lead to a wider acknowledgement of the social dimension of construction projects (Hutchins and Sutherland, 2008b).

Finally, other research topics found include the relationships between stakeholders and the ethics underlying them (Moodley et al., 2008, Vee and Skitmore, 2003), resilience and sustainability (Bocchini et al., 2013, Zhang and Dong, 2011), the adequacy of buildings to context's characteristics such as tradition (Braz et al., 2011, Kaklauskas et al., 2005), factors affecting construction delays (Siva Subramani et al., 2016) the importance and benefits for communities of built heritage and its conservation (Nesticò et al., 2018, Tweed and Sutherland, 2007) and informal settlements (Caballero Moreno et al., 2018).

3.4. A framework to understand the relationships between civil engineering and social aspects

The results of the literature review show that there exists a large amount of literature on topics concerning the intersection between infrastructures and social topics. Every subfield of CE and of SSH is related to each other dually, heterogeneously and dynamically. The dualism comes from the fact that infrastructures shape and are also shaped by society. The heterogeneity stems from the fact that certain connections are stronger than others. Finally, the relationship is dynamic because it changes under different circumstances. Actually, from the reviewed literature it is possible to observe that for a specific relationship between one type of infrastructure and a social dimension, the kind of effect produced will be defined by three main variables. These variables are referred to as externalities and are the following ones:

- **Stakeholder**: the effects that are produced as a consequence of the interaction between CE and the different SSH domains depend to a great extent on the stakeholder that is considered (user, engineer, local community, society, value chain actors, etc.).
- **Time**: the type of impact produced depends on the stage of time of the infrastructure considered. In general, we can assume that the existing general stages in the lifecycle of infrastructures are: planning and design, construction, operation and maintenance and decommissioning.
- **Others**: finally, apart from the factors related directly to CE and SSH, and from the ones concerning the lifecycle and the stakeholder, other aspects can also influence the kind of relationship between SSH and infrastructures. Examples of these aspects are natural hazards or different geographic locations.

Hence, the relationship between the two scientific fields can be described three-dimensionally. While the matrix that would represent all the intersections between subfields of CE and subfields of SSH is two-dimensional, all these intersections are at the same time characterised by the three above-mentioned variables. This gives rise to what is shown in Figure 3.4 as a cube. The cube is further broken into smaller cubes that represent specific intersections between CE and SSH.

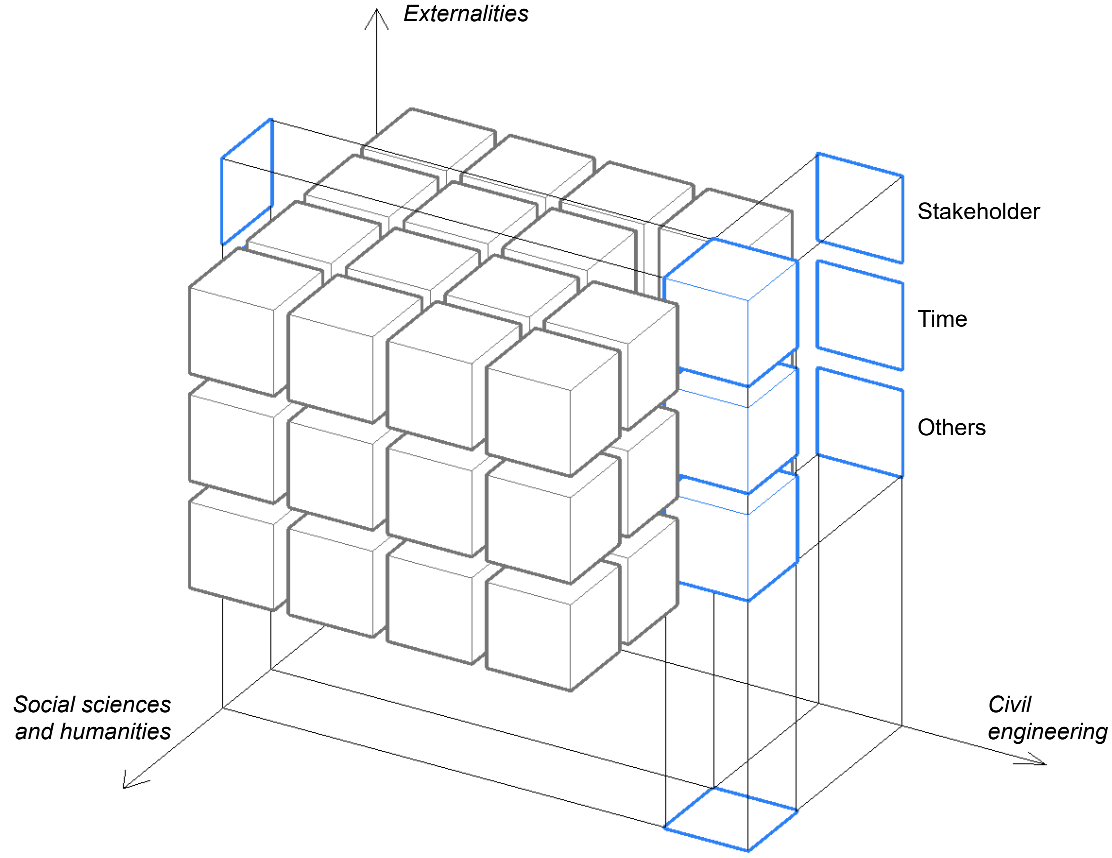

Figure 3.4. Representation of the relationship between CE and SSH

3.4.1. Description of specific relationships

This subsection aims at describing the factors concerning the duality of the relationship between infrastructures and SSH. From the performed review, it has been possible to identify and classify all the intersection points between CE and SSH. They are illustrated in Figure 3.5. This figure shows the duality of the relationships, as well as the topics through which CE and SSH are connected, grouped in different categories.

However, it must be emphasised that current literature does not cover all the relationships that are shown in Figure 3.5. Namely, there exist research gaps in some of the connections between CE and SSH. For instance, even though we have detected that social aspects can influence the construction of tangible culture, no publication has been found with this regard.

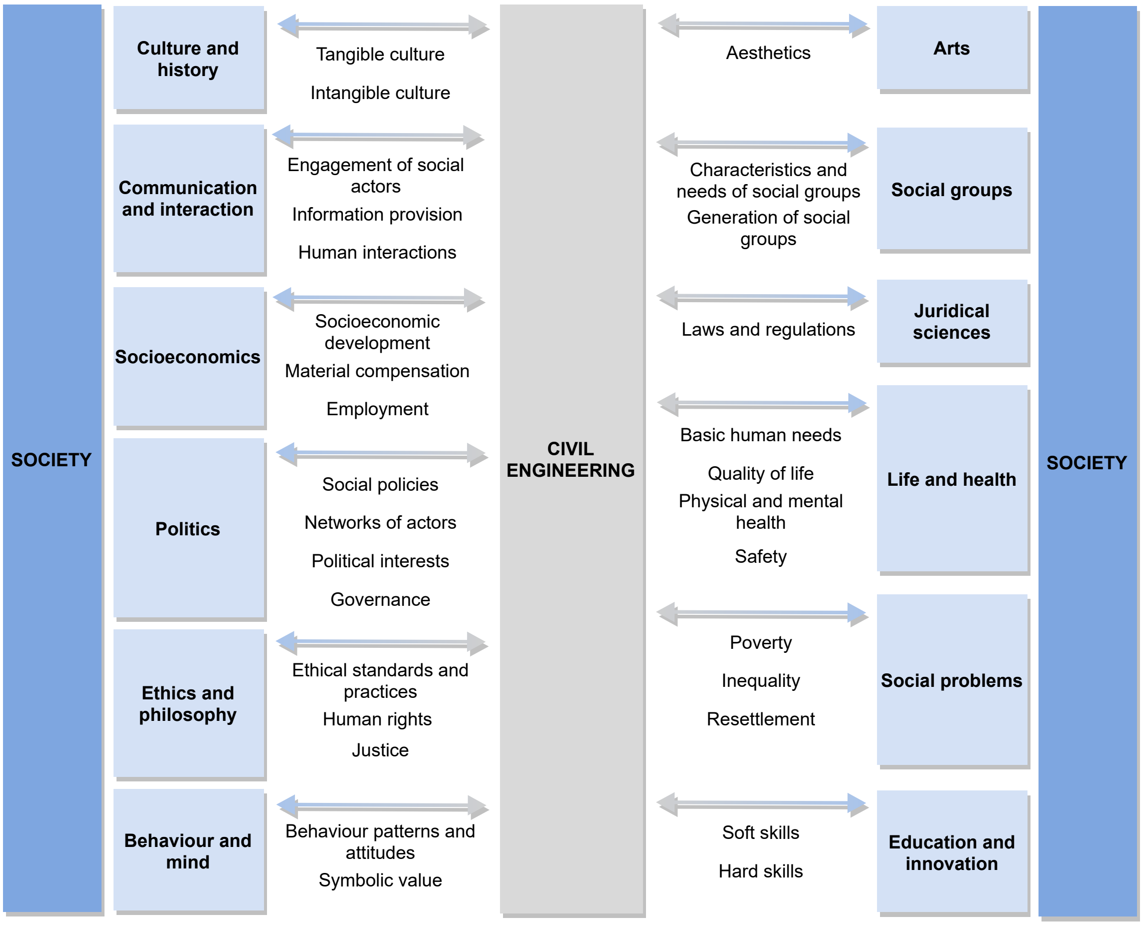

Figure 3.5. Diagram showing the classification made for each social category

3.4.1.1. Culture and history

The social factors associated with culture and history that have been found in the literature can be classified into two subcategories: tangible and intangible culture. First of all, as for tangible culture, urban nuclei or, in general, any human construction, are places where human culture reaches its maximum level of concentration. Infrastructures tangibly represent expressions of human culture and allow to materially preserve aspects such as diversity, habits and values, human aptitudes or interests. As such, any CE work functions both as a driver and as a generator of culture. This aspect includes cultural heritage buildings; even though these structures have usually attracted more attention in the field of culture, tangible culture is not limited to them.

Secondly, these palpable representations of culture are at the same time shaped by intangible culture. This includes cultural characteristics such as customs, traditions, values, norms, attitudes, etc. that may mould the behaviour of human social groups and that are passed down from generation to generation. For instance, these groups can be tribes, ethnic groups or local communities. These characteristics have an effect on the way certain individuals and collectives make use of infrastructures; hence, will have different effects on their demand and use, which is, therefore, a factor to consider in the design and planning of CE works.

3.4.1.2. Behaviour and mind

One aspect that has been considered in the literature in the dimension of behaviour and mind are behaviour patterns and attitudes. Individual and collective behaviour patterns and attitudes have an impact on the demand and use of infrastructures. This makes it necessary to carry out the design phase according to these needs and characteristics in order to make infrastructures as adequate as possible to their context. Once the structure has been built, it can generate new behaviour patterns that did not exist previously, such as the way individuals travel, consume, spend their free time, etc.

Besides, some authors have also emphasised the symbolic value of infrastructures: CE works can generate feelings of belonging or of local identity, as well as can change how individuals experience and sense places.

3.4.1.3. Social communications and interactions

As for social communications and interactions, three main areas are the ones that can be found in publications: the engagement of social actors, the provision of information and human interactions.

First of all, the engagement of different stakeholders in the different stages of the lifecycle of the structure includes both the direct participation and the consultation of social actors, such as citizens or citizens organisations and expert committees. Taking into consideration the opinions and knowledge of these stakeholders can result first of all in better-informed decisions; also, it can also benefit the general acceptance of the project.

Secondly, another factor that is englobed in the relationships between stakeholders and that may also favour the project's acceptance concerns the flow of information existing between the civil engineers in charge of the project and the future users and the local community that are affected during the different processes.

Finally, infrastructures have effects on the spatial mobility of people. This impact on spatial mobility and social interactions should always be globally positive or, at least, neutral. However, even though in some cases mobility and the ease of social interaction are positively modified, restriction of physical displacement of people and their interactions can occur as a consequence of infrastructure development too.

3.4.1.4. Juridical sciences

Projects are always bounded by laws and regulations at several different areas such as the relationship between employer and employees (contract procurement, contract conditions, professional conduct, dispute resolution) or the design of the project itself (building codes). Even though they usually have a major effect during the design and planning phase. Actually, special projects or new technologies (such as new materials) introduce new scenarios that maybe weren't contemplated before, which leads to the need for developing new juridical frameworks accordingly.

3.4.1.5. Life and health

The enhancement of people's life and health is one of the social aspects for which there is generally more agreement on. In this study, we decompose this factor into four different areas: quality of life, physical and mental health, safety and basic human needs.

The impact that infrastructures can have on society is huge. This impact can either be positive or negative and therefore affected stakeholders can go through an enhancement or a worsening of their quality of life, health and basic needs coverage due to infrastructures. Besides, the consideration of occupational and workplace safety and health are crucial in CE, since civil engineers work in potentially dangerous conditions; at the same time, civil engineers work to design and construct projects that are to accommodate large amounts of people and therefore, a failure in their design can have serious concerns for the surrounding population.

3.4.1.6. Politics

Three main areas that have been identified in this dimension are social policies, political interests and networks of actors.

First of all, social policies should aim at protecting these rights, as well as enhancing the quality of life of all society in general. Besides, these policies should attempt to develop infrastructure that is both resilient and sustainable. Sometimes, political interests might influence what project is chosen or how it is designed, which can have effects on the performance of these projects. These political interests might be linked to the development of social policies that establish guidelines as for what and how infrastructure projects are developed. Existing literature has also dealt often with the generation of networks of actors as a result of the different stages of the lifecycle of the infrastructure, and how they are involved in the project and what their weight in the final decision is.

3.4.1.7. Ethics and philosophy

Ethics has been considered by many as a cornerstone for CE professionals. There exist regional codes of ethics that have been developed with the aim of serving as a model for professional conducts. For example, the code of ethics of the American Society of Civil Engineers advocates the "integrity, honour and dignity" in the profession and establishes a collection of fundamental canons to be practised such as the continuation of professional development or a human treatment that is fair and equal. Apart from standards applied to the profession, also aspects of justice and human rights need to be considered in the development of projects, since infrastructures can put key human rights at risk; examples of this are the forced resettlement of communities or threats to life and livelihoods due to the use of land or other resources that local communities were dependant on.

3.4.1.8. Arts

Visual arts, contrary to what was considered a decade ago, not only includes fine art like painting and sculpture, but also anything that has an expressive component that is mainly visual. Built environments generate a visual impact on their surroundings and they create emotional responses in individuals' minds, which can be positive (attraction), negative (rejection) or even neutral. Additionally, there is a clear aesthetic element in the design process of any infrastructure that is influenced by factors such as the designers' art sensitivities or current artistic movements (like Art Deco, Art Nouveau and Bauhaus). During the operation of the infrastructure, generally no significant modifications are made to it; nevertheless, other art forms such as street art might alter its appearance.

The aesthetic component of infrastructures is predominantly dynamic. Through the perceptions of individuals across generations, the attitudes towards a built work change. There are, also, buildings whose material characteristics and design or whose context (such as climatic) are such that their appearance changes over time; this, also, adds up to the dynamism of its aesthetics. An example of this is the Guggenheim Museum in Bilbao (Spain).

Finally, apart from visual arts, there have been attempts at developing infrastructures with an audio-visual impact instead of visual solely. These infrastructures are scarce in the present.

3.4.1.9. Social groups

Civil engineers need to consider the particularities and necessities of different social groups, which will affect the demand of the infrastructures they are designing. These groups are defined by varied characteristics: gender, age, socioeconomic class, location, etc.

At the same time, engineers also need to realise that their projects will somehow have an impact on how these groups interact between them, leading to a possible generation (or destruction) of certain social groups.

3.4.1.10. Social problems

This category is a dynamic one in the sense that as society evolves and CE develops new methodologies and infrastructure types, new social problems might arise, as well as existing social problems can be more easily avoided. From the performed review we have identified two main areas: the resettlement of people and poverty and inequality. As for the last one, there is a clear relationship between poverty and inequality and infrastructures that this has been widely analysed in the literature.

3.4.1.11. Education and innovation

Two main aspects have been identified regarding education and innovation. First of all, practitioners from all fields need to develop soft skills due to the fact that for better integration between SSH and CE it is essential that both academicians and practitioners work in multidisciplinary fields and are able to effectively communicate ideas to non-experts. These skills include cultural awareness, communication and teamwork. Secondly, it is also necessary to consider the hard skills that are needed in order to adequately integrate CE in a comprehensive social framework (and vice versa).

Differently to the previous social dimensions, education and innovation have additionally driver functions, since they bridge and transmit the knowledge between SSH and CE.

The great majority of publications found dealing with the relationship of education with CE did so in general terms and did not consider the subcategories defined for infrastructures (Bacon et al., 2011, Becerik-gerber et al., 2011, Bowman and Farr, 2000, Grigg, 2018, Lozano and Lozano, 2014, Passow, 2012, Russell and Stouffer, 2005, Watson et al., 2013), except for a small group of publications which mainly dealt with environmental engineering in relation with sustainability (Dimitrova, 2014, Kováč and Vitková, 2015, Panero et al., 2018, Schmidt et al., 2018, Taylor et al., 2007).

3.4.2. Use of the framework

All the concepts presented with regard to the relation existing between infrastructures and SSH can be used as the basis for further work at different levels. The diagram shown in Figure 3.4 can be seen from different perspectives from which various ways of analysing the relationship stem. These have been illustrated in Figure 3.6. One can both analyse specific relationships between fields and subfields of both CE and SSH and transversal relations that concern either all the social fields or all the infrastructures fields. For example, governance and inequality are social topics that can be studied transversally, since it concerns all the fields in CE. When analysing specific relationships, it is possible to carry out the analysis globally (considering all the lifecycle stages and all the stakeholders) or more particularly by examining only one or few stages and involved actors.

The classification established, together with the conceptual framework described, can be useful for both practitioners and academics. On the one hand, practitioners can use the concepts developed to structure criteria in decision-making processes, as well as to quantitatively and qualitatively evaluate impacts from CE projects and carry out thorough Life Cycle Analyses. On the other hand, in the academic field, it can be used as a guideline for the structuration of syllabuses of CE higher level education; this can be implemented in specific subjects, or it can be incorporated transversally throughout all the academic years in all the subjects. Additionally, the performed review can be used by researchers to study specific relationships that have not yet been deeply investigated.

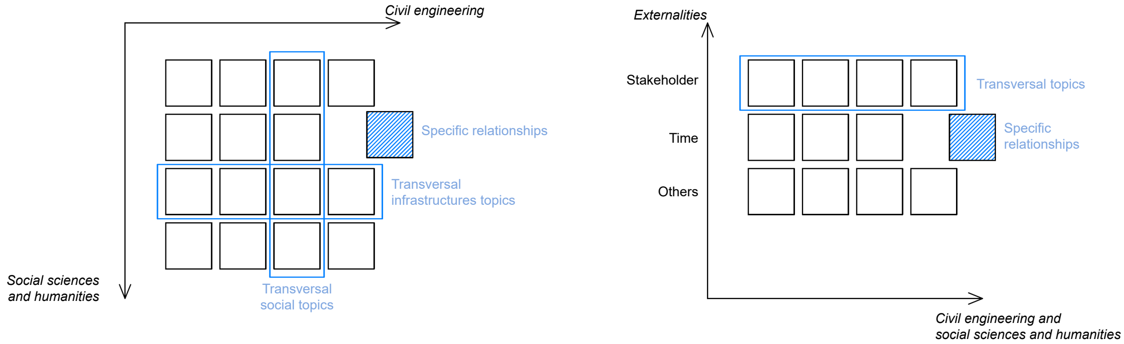

Figure 3.6. Top view (left) and front view (right) of the diagram in Figure 3.4

3.5. Summary

In this chapter, the conceptual framework of the thesis was presented. First, the context of interdisciplinarity in higher education was discussed. Then, the relationship between the social sciences and humanities and civil engineering from a holistic point of view was discussed and a conceptual framework was proposed. For this, a thorough and systematic literature review of the literature in the intersection between the two fields was carried out. In order to do so, subfields of civil engineering and of the social sciences and humanities were first defined and a taxonomy for each of them was established.

Based on the review, first of all, the subdomains for each of the scientific fields that were established were checked to ensure that they encompassed all the existing concepts in the literature. Secondly, the review allowed establishing a framework that describes both qualitatively and quantitatively the relationships between the scientific fields.

The relationship between civil engineering and social sciences and humanities can be represented three-dimensionally by considering the externalities that characterise the specific intersections between subfields. These factors are: the stakeholder from whose point of view the relationship is analysed (user, local community, society, worker, etc.); time, which is usually defined through the different stages of the lifecycle of the infrastructure (design and planning, construction, operation and maintenance or decommission); and other possible externalities.

Besides, the relationship is dual, heterogeneous and dynamic. First, the duality is given by the fact that infrastructures both shape and are shaped by social processes; secondly, it is heterogeneous because the strength of the relationship is not the same in all the intersection points; thirdly, it is dynamic because it changes affected by factors such as time.

Not all the specific relationships have been studied at the same level. Social topics such as governance, justice and vulnerability have been most widely studied in relation to civil engineering; as for infrastructures, the field that presents the greatest amount of research on social topics is transport. When it comes to education, much of the research done until the present in the intersection between the social sciences and humanities and civil engineering has focused mainly on the inclusion of concepts related to sustainable development in curricula and lifelong learning programs.

4

A global perspective to the "social" in civil engineering education

This chapter is partially based on the following article:

Josa, I. & Aguado, A. (2021). Social sciences and humanities in the education of civil engineers: current status and proposal of guidelines. *Journal of Cleaner Production*, 311. DOI: 10.1016/j.jclepro.2021.127489.

The doctoral candidate contributed 90% of the work presented here.

4.1. Introduction

In this first empirical chapter, the situation of integration of relevant content from the social sciences and humanities in civil engineering programmes is analysed from an international perspective. It needs to be said that despite the importance that several authors have attributed to understanding the engineering profession as something far from being purely technocratic, engineering schools seldom introduce learning areas about people and the social side of engineering (Trevelyan, 2014). In fact, several authors have analysed the integration (or lack of integration) of social issues in engineering education. Lucena and Leydens (2015) examined some of the barriers and opportunities for integrating social justice issues in engineering courses.

Besides the work by Lucena and Leydens (2015), the inclusion of social issues in engineering education has also been analysed by other authors and for other social dimensions, such as public welfare (Niles et al., 2020), intercultural relationships (Kudo et al., 2020), ethics (Corple et al., 2020), or social sensitivity (Walther et al., 2020). Drawing from their results, some of the implications for engineering education that they detect are the introduction of reflexive principlism in engineering education as a means of developing ethical reasoning, challenging the replication of explicit and implicit technocentric norms in engineering, or increasing the interaction between students and other stakeholders, such as users or practicing engineers. Other related studies in this research line include the analysis of innovative practices in HE institutions (Cai, 2017, Leydens and Schneider, 2009, Ma and Cai, 2021).

A common factor in the literature dealing with the integration of social issues in engineering education is that they primarily focus on students' learning and thinking processes. Despite this, the role that educators have in student transformation is indispensable. Academics have a critical role in teaching and assessing curriculum and are therefore responsible for furthering university graduates' skills development. Hence, even though it is fundamental to understand students' perceptions, it is as well important to identify the hindrances to curriculum change in relation to bridging the gap between the social and the technical.

In light of the above, the objectives of this chapter are twofold. First, the chapter aims to analyse the current status of social sciences and humanities in formal HE civil engineering programmes. For this purpose, perceptions regarding social sciences and humanities from professors at civil engineering faculties around the world are examined, the way in which 100 universities include social aspects in their curricula is analysed, and a review of accreditations and agreements that consider the incorporation of the social sciences and humanities in civil engineering is presented. Secondly, this chapter aims to contribute to the discussion on the need to include social aspects in STEM and, in particular in civil engineering.

The results are discussed following four major themes that were defined following the coding of the collected data: ability, preparedness, willingness, and propitiousness to change. These four factors are represented in Figure 4.1, together with the sub-themes that will be discussed throughout the chapter.

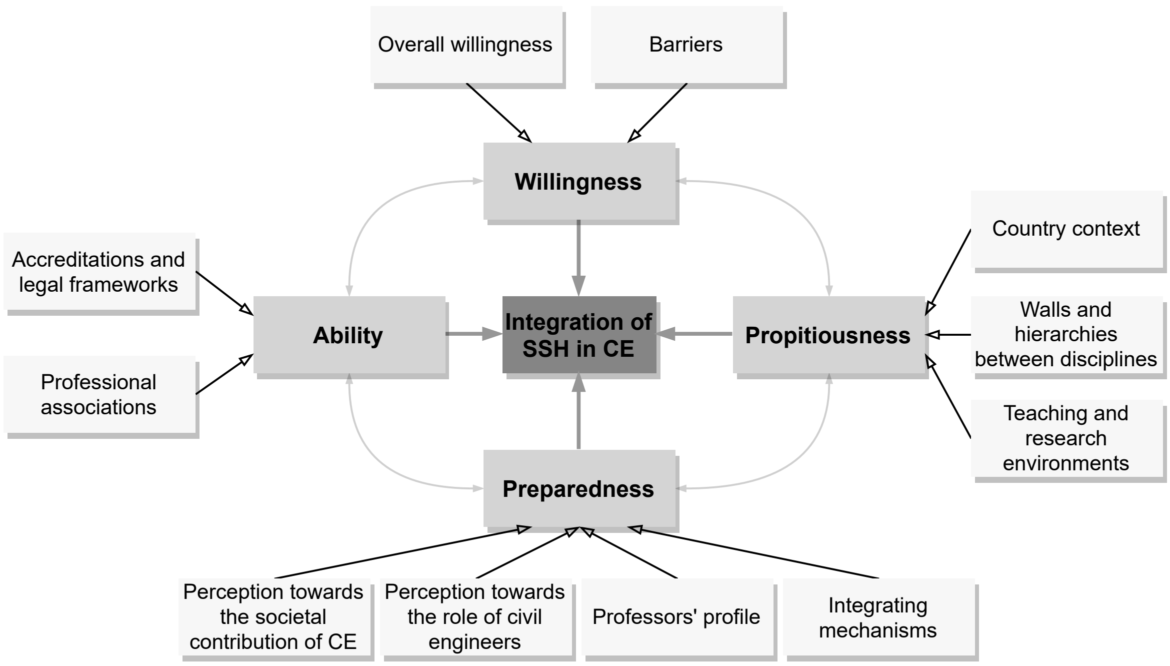

Figure 4.1. Themes analysed of the GT-based model for the international case

4.2. Ability to change: legal and institutional frameworks

The ability to integrate social aspects in curricula may be hindered by various external constraints. On the one hand, accreditation bodies and legal frameworks may be establishing criteria or requirements that set the task of making changes in HE programmes difficult.

On the other hand, in some countries, civil engineering professional associations play an important role in shaping the education of future civil engineers. They have the potential to heavily direct and influence curricula, and therefore examining such power is relevant to understand the process of integrating relevant content from the social sciences and humanities in current civil engineering programmes.

The results related to these two main aspects are described in more detail in the following subsections (Section 4.2.1 for accreditations and legal frameworks, and Section 4.2.2 for professional associations).

4.2.1. Accreditations and legal frameworks

Education accreditation profoundly influences the interdisciplinarity of civil engineering programmes and, in particular, whether to include social content. The accreditation of an engineering programme makes it possible to evaluate and verify the quality of its services and operations through a quality assurance process. Accredited status is granted if the set standards are met. Regarding this, there are multiple accreditation criteria, not only related to an engineering education programme's social sensitivity. However, examining these criteria can give a better understanding of the overall relative importance that the social sciences and humanities are given in an engineering programme.

In this thesis, the aspects within the various existing accreditation criteria that have been analysed are the specificity and depth of the consideration of social aspects. As specified in Section 2, a distinction is particularly made between the so-called more general transferable skills and the technical skills related to specific areas of the social sciences and humanities. Accordingly, this study examines the importance given to both types of skills as students' outcomes. As for the former, it needs to be noted that there is no agreed framework on what specific transferable skills are necessary for civil engineers. For instance, Suñé Grande and Bonet Àvalos (2014) consider five social competencies in engineering education: human interaction and versatility, facilitative leadership, teamwork, responsibility and active learning and initiative and innovation.

Before introducing the different accreditations in detail, it is important to emphasise that there are worldwide education agreements to recognise the equivalence of agreement signatories' accreditation systems. Two of the most widely known agreements in the field of engineering education that apply to civil engineering are the Washington Accord (established in 1989) and the Sydney Accord (established in 2001).

Regionally and internationally, two accrediting bodies stand out: ABET and the European Network for Engineering Accreditation (EUR-ACE). First of all, ABET accreditation identifies seven learning outcomes that students should attain during the programme: identification; formulation and solution of complex engineering problems; application of engineering design to produce solutions that meet various needs (safety, welfare, economic, environmental, social, etc.); effective communication; recognition of ethical and professional responsibilities in engineering situations and consideration of their impacts in different contexts; effective team-working; appropriate experimentation, analysis and interpretation of data; acquisition and application of new knowledge as needed.

Even though ABET criteria up to the year 2000 required inclusion of half a year of studies on humanities and social sciences in engineering studies, this was subsequently removed (Evans et al., 2007). Therefore, at present, even though transferable skills are considered in the accreditation criteria, technical knowledge on social sciences and humanities is not. Among the students' outcomes, it is the second one that reflects a possible influence of social aspects in curricula to a greater extent, which describes “an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.”

The EUR-ACE framework provides standards and guidelines for engineering programmes and identifies eight learning areas: knowledge and understanding, engineering analysis, engineering design, investigations, engineering practice, making judgements, communication and team-working, lifelong learning. On the one hand, technical knowledge on the social sciences and humanities is not systematically considered in the criteria for accreditation; it is only in the outcome “Making judgements” that social issues are considered, albeit superficially and lacks a specific definition of what this involves. On the other hand, transferable skills do appear as a requirement that students need to demonstrate by the end of the degree.

At local and national levels, other outstanding accrediting bodies include Engineers Australia, National Board of Accreditation of India, Japan Accreditation Board of Engineering Education, Institute of Engineers Singapore, Accreditation Board for Engineering Education of Korea, Engineering Accreditation Council of Malaysia, Institute of Engineering Education Taiwan.

While only a few of these accrediting bodies incorporate specific technical knowledge on social sciences and humanities as required students' outcomes in the curricula of civil engineering programmes, most of them do include acquisition of certain transferable skills as a requirement.

For instance, in the Stage 1 competency standards for professional engineers for the Engineers Australia accreditation, what are referred to as human factors are included in two learning outcomes (learning outcome 1.5d, "Is aware of the founding principles of human factors relevant to the engineering discipline" and 2.3b, "Addresses broad contextual constraints such as social, cultural, environmental, commercial, legal, political and human factors, as well as health, safety and sustainability imperatives as an integral part of the design process"). The National Board of Accreditation of India incorporates the outcomes required by ABET, including the one emphasised beforehand, which is related to the consideration of social factors when designing engineering solutions.

However, in spite of the requirement for students to demonstrate knowledge and awareness in broad social sciences and humanities areas, there is no guide on the right level and approach with regard to including social sciences and humanities in engineering curricula. This leads to the question of breadth and depth of the integration of social aspects in the education of civil engineers.

Research on the distinction between technical depth and interdisciplinary breadth in engineering programmes is still in its infancy. Sanchez et al. (2016) examined ways in which hydrology students could achieve a T-shaped profile through teaching concepts and doing activities established within real-world contexts and data. They did so through what they called data and modeling-driven geoscience cybereducation (DMDGC) standardised modules.

Blewett (1993) specifically dealt with the issue of introducing social sciences and humanities in engineering education. In his article, he described the process of reform of engineering education in a HE institution. He concluded that breadth could be obtained in lower level courses, while this would reinforce depth in upper level courses.

As an exception, the Canadian Engineering Accreditation Board does have a requirement on the inclusion of social sciences and humanities (Canada, 2019). It sets a minimum number of credits corresponding to "Complementary studies". Such studies may include "humanities, social sciences, arts, languages, management, engineering economics and communications."

4.2.2. Professional associations

In addition to accrediting bodies, there are numerous engineering education organisations and civil engineering professional institutions. They exist at different levels, ranging from local to international. Even though their relationship with university programmes is not as direct as that of accreditation bodies, they can play an essential role in the development and improvement of engineering education. They can also raise awareness on important issues for engineering education and the engineering profession, both among engineers and society. For instance, at regional levels, the European Society for Engineering Education (SEFI) and the American Society for Engineering Education (ASEE) are two of the best-known ones. Publications by both organisations showcase the need to incorporate a social dimension in engineering curricula (see, for instance, Adair and Jaeger, 2011, Nahas and Moubayed, 2015, Titus et al., 2011, van Hattum-Janssen et al., 2012).

It is also possible to find professional associations for specialised fields of engineering, such as ASCE and ICE. ASCE in particular has been boosting explicit inclusion of social factors in the education of engineers. They have developed a Body of Knowledge and advocated for considering the technical capacities of civil engineers as represented by four pillars: basic sciences, mathematics, humanities, and social sciences (Evans et al., 2007). Besides, "the vision for the civil engineer in 2025" (ASCE, 2007) stresses several aspects whose study is closely related to social sciences and humanities. This document describes a roadmap for the civil engineering profession through five outcomes, which are respectively entitled "Master builders", "Stewards of the environment", "Innovators", "Managers of risk", and "Leaders of public policy".

In a similar vein, ICE has published a document defining its vision and strategy for the 2013-2025 period, under the title "Shaping the world" (ICE, 2013). This document still emphasises the role that civil engineering plays in achieving most sustainable development goals and in tackling some current global challenges which, the document states, are social, environmental and economic.

In fact, a few participants in the interviews mentioned the role of civil engineering associations in the civil engineering education panorama. In particular, Engineers Australia and ICE were frequently brought up.

As for Engineers Australia, interviewees that mentioned it had a positive perception towards the role that it had in defining specific social competencies for civil engineering programmes. As one of them described,

> "the Australian professional association has published a code of ethics for... quite a few years now. And more recently, in 2014, they also published a sustainability policy and they have now a more comprehensive document with guidelines for sustainable engineering and ethical engineering. And that very clearly says, you know, that we cannot only look at the economic benefits, but also at social and environmental impacts. And they do have guidelines for what needs to be included in the education of an undergraduate engineer. It also needs to meet these guidelines and they include ethical codes and also a fair bit on soft skills, like presentation and so on. And our courses need to demonstrate that they address these skill sets. So you need to normally show that your course includes something on presenting your topic or talking about it or writing about it. So yes, that's [social competencies] very much included."

The question of the skills that engineers should develop during their training will be discussed in more detailed in Chapter 6. In addition to the reference to Engineers Australia and the issue of skills, the words of this professor reflected a connection between the integration of social aspects in the programmes and the question of sustainability. In fact, this is an important issue because the awareness of faculty members towards the topic of sustainability can render the integration of social aspects more propitious. A whole subsection will be devoted to this subject for the case of Spain (Section 5.5.1).

Regarding ICE, an interviewee that had been the school director in the past talked about the barriers that the association had posed when trying to change the curriculum. According to this participant, changes are not usually considered in programmes because their accreditation depends on the approval by this institution. As he explained:

> "I suspect that most faculties, I have no evidence for this at all, but I suspect that most faculties have a few people in it who would be very interested in the outcomes. And it's very difficult

> for them to penetrate the system because the system is very hardwired, often controlled by professional institutions. I had to deal with the professional institutions. And they are often scared of the professional institutions because they can take the degree away. So we have accreditation. This institution has to say, yes, you are accredited with that. And so they, they called me down to the institution of civil engineers and they said: do you expect this so called degree to be accredited? And I thought, well, the only way to answer this is by being very strong. So I said, well, if I think that your accreditation is worth having, then I will think about it. And they were horrified. They said to me that nobody had ever spoken to them like that. And, I remember, the reason I said that to the institution was, cause I knew that at the end of the day, if they didn't accredit the degree, we would still have students and it wouldn't make any difference to them whether we had an accredited degree."

This interviewee believed that there was people in the majority of civil engineering schools interested in making this type of changes in the curriculum. Nonetheless, as he argues, this becomes a complex task due to the difficulty of going through the system[1]. He also added the following:

> "I remember, the president of the Institution of Civil Engineers came to see us because he said he had just become the president, and somebody had told him he'd better come and see us because this was a troublesome university. So he came and asked me a whole load of questions and things"

The same participant described that, in the end, the members of the institution became more supportive and allowed the curricula changes to happen. Nonetheless, his experience reflects the resistance to certain changes that some institutions or associations have. In fact, Power and Handley (2019) found that resistance to change is one of the main barriers to interdisciplinarity in HE.

4.3. Preparedness to change

Even when the accreditation criteria, legal requirements and professional associations facilitate the task of integrating social aspects in civil engineering programmes, the different stakeholders involved in such integration may not be prepared to make such changes.

This is why understanding if the main stakeholders involved in these processes are prepared to integrate social aspects, which implies, for instance, modifying the contents of what they teach or understanding well the need existing for such integration and the theory behind it.

This section starts by discussing the perceptions that exist among the interviewees regarding the societal contribution that civil engineering has, as well as their perceptions towards the role of civil engineers in society. This is particularly relevant to understand how different perceptions may create barriers or facilitate the processes of making changes in the educational programmes. Then, the detected differences existing among professors related to their characteristics are discussed. The last subsection analyses the different mechanisms for integrating social aspects in civil engineering programmes that exist in different universities.

4.3.1. Perception towards the societal contribution of civil engineering

When asked about the societal contribution of CE, responses were diverse. Nonetheless two different paradigms arose regarding the role that civil engineering has within society. On the one hand, some interviewees argued that civil engineering plays a role of enabling quality of life. Namely, that civil engineering works create the conditions that are favourable to achieve an effective and efficient quality

[1]This issue will be discussed in more detail in Chapter 5.

of life among citizen, and serve to facilitate it. On the other hand, the responses of some interviewees reflected that they perceive infrastructure as a driver of quality of life. Namely, that civil engineer is directly responsible for the provision of quality of life to citizens.

In relation to civil engineering as an *enabler*, one interviewee said the following:

> "I guess civil engineering contributes to society in an unseen way. It's not something that general people in communities would see, but ultimately it'd be particularly in urban environments, but also in, you know, in all communities. I think civil engineering is actually key to societies operating in the way that people have come to expect in terms of delivering infrastructure that allows us to achieve the levels of health and employment and all these things that we've come to rely on."

As it can be seen, this participant saw the role of civil engineering as something "unseen" but giving a support to achieve certain quality of life goals. The fact of such role being directly imperceptible is relevant for the state in which the profession is perceived and valued within society, which will be discussed in more detail later on.

Regarding the perception of civil engineering as a *driver*, a professor talked about the ways in which it can have multiple societal contributions, including the provision or access to various basic services:

> "I think that civil engineering has a lot of positive contributions to society by providing, you know, basically some things that are very basic needs and for housing and healthcare and transport and all the things that society really needs to function in a modern way."

The same participant also recognised that this role of quality-of-life driver is not always fulfilled and, in fact, it sometimes worsens the state of such society's life's quality. In his own words:

> "I think that there's a tendency for civil engineering to assume that the contribution is all positive and it isn't always, or at least it can bear some reflection of... 'really, is it positive or isn't it', you know, to consider what maybe some of the negative consequences are or the alternative to the way we currently do things that might be even more positive for society than what it's done with the plan initially."

In addition to the perspectives of civil engineering as a quality-of-life driver or enabler, there was a minority of participants that discussed the fact that civil engineering is at the same time modifying the way we live. One of these interviewees put it as follows:

> "Overall, I think civil engineering has an enormous impact on society. You see it everywhere you look. I'm looking around right here and I'm seeing a whole heap of it. It's probably of prime importance with regards to how society behaves. And I think at the moment what's happening is that civil engineers are being expected, not just to build the buildings and things like that, but there's an increased focus on... them being able to guide society to certain ideals, be it sustainability or ethical considerations of certain things."

Having said this, no matter what the specific perception towards the contribution of civil engineering was, most participants agreed that there would be an added value if civil engineers understood better the context where their projects sit. This aligns well with one of the four rationales for integrating social aspects in the education of civil engineers that were presented in Chapter 1. This was expressed as follows by a professor:

> "I think if you don't understand the fundamental principles of mathematics and physics behind

the infrastructure, you won't be able to do your job properly. So that foundation needs to stay, I guess, as it is.

But I think they [civil engineers] would benefit from having just this kind of bigger picture and, you know, to kind of understand, I guess the society as a whole in a sense, especially because of that kind of, again, what I mentioned, thinking about the longer future, and how what we do now could have an impact in the future. Not just, you know, bringing this kind of short term benefits, but kind of working now, but actually enabling people who will live in the future to have at least similar quality of life. Again, I don't know, I mean maybe, maybe this type of thinking is more relevant for people who are a bit older. I guess when you're young, you are,... you don't think too much in advance. I guess there is a bit of that. So, so I guess finding a way to get them to understand that social context of the role of infrastructure within the society that I think, you know, is a fundamental thing.

So I don't think they need to really know too much about it, but I think they would really need to understand that, infrastructure in that wider context."

As it can be observed, this participant concluded by saying that there is not a need for a deep knowledge of the social sciences and humanities, but for a superficial understanding of basic concepts that are related to infrastructure. The difficulty in finding a balance between the two extremes (highly specialised knowledge and no knowledge at all) was, in fact, frequently mentioned by several participants[2].

4.3.2. Perception towards the role of civil engineers

Regarding the role of civil engineers, data from the interviews reflected that there is a more conventional way of thinking of the profession focused on the science at the core of civil engineering and its subdisciplines, and which was related by the participants to professionals with a narrower perspective. This translates into educational programmes, as a professor from the United States put it:

"Technology is changing the capabilities of civil engineering. I think that in academia, in the United States, there is a big spectrum. So, there are some programs that are very avantgarde and are changing with the times, and understanding what society might need. And then, because engineering is a very old field and tradition, there are many programs that have,... that are very archaic and are not incorporating new concepts. like maybe they don't use a system design or maybe... they, you know, don't incorporate technology, or communication. So, I think it's a large spectrum."

Regarding how this is being reflected in industry and higher education, this participant explained what follows:

"I do think that, in practice, it is changing, but in academia, I think some programs are not. And some are. I also think that there are,... I think that it's probably not just in the United States, but, but I think that there are, you know, like ABET, the accreditation in the United States,... I think that there are different governing bodies and organizations that have some have done a better job than others in modernizing curriculum and modern modernizing, programs."

The idea that the participant above reflected in terms of how less conventional civil engineering is more prepared to solve social problems and to adapt their works to societal contexts was shared by most participants. In the contexts of China and Australia, another interviewee mentioned:

[2]This links, again, to the question of breadth and depth that is essential for understanding the contribution of the social sciences and humanities in civil engineering education. A review of literature on this question was presented in Section 4.2.1.

> “I guess if you’re picturing like a dam or something like that... you’ve got the people who might want to use the water, whether they happen to be industry or agriculture or mining. And then you’ve got communities and the different uses of water within those many different stakeholders. Then you’ve got the people that are impacted by the infrastructure construction. So, you know, you have to relocate people when you put in three dams in China or, you know, we’ve had similar projects in Australia for hydroelectric schemes where whole towns have been relocated. So you’ve got stakeholders in terms of possibly people who may or may not be beneficially impacted by the infrastructure, but who are definitely negatively impacted. You’ve got indigenous users who have cultural, I guess, meaning in the landscape and connections to the landscape that are not well considered in terms of our traditional ways of designing infrastructure.
>
> And then you’ve got the environment that has no voice, but is incrementally impacted by all of these different projects, as well as all the different government planning departments and their different interests in terms of political motivations, as well as bureaucratic technical kind of considerations as well.”

In fact, the more narrow-minded profile of civil engineer taught through a more traditional curriculum was seen as opposed to a civil engineer who is more flexible and capable of solving problems from a holistic perspective.

At this point, it is interesting to note that the conventional way of thinking of civil engineering in HE programmes was related by some professors to more traditional ways of lecturing and, in general, of seeing education. One participant talked about the activities that they do during different terms, and made a contrast between this traditional lecturing and a way of teaching in which they teach about social aspects. In his own words:

> “So, we basically have two terms, and then each one of them divided, the reading week for five weeks, four times, five weeks. And,... it’s sort of evolved from that, but originally it was, we would have four weeks of, of more or less traditional lecturing. And then we would have a scenario week where all of the theory that the students get taught is applied in some kind of problem. And we would also try and incorporate social aspects and transferable skills.
>
> And since we’ve done that, I have found that the students are much... I think that is really what has made them much more mature and well-rounded because they are put into an almost realistic kind of situation. I mean, they’re very simplified things, obviously, if they only do them for a week. But they,... it’s kind of an experiential thing.”

Besides the specific contribution to society that civil engineering makes, participants also discussed what the “social” side of civil engineering really involves and what the role of civil engineers is. Several participants viewed this as a form of transversal skill of engineers rather than knowledge in technical areas or disciplines. When asked about his perceptions on the social in civil engineering, a professor answered as follows:

> “Depends what you mean by social? One of the things I do is take my students away for a week of field work. So we live and work together for a week. So when they’re eating breakfast, eating dinner, eating meals, working day and working nights, sleeping in the same bunks, that’s social in a sense. Yes. It depends what you mean by social. It’s not learning music. It’s a bit of a social, sort of a side of things.”

Such vision matches well with the idea that Arienti and Marfisi (1978) reflected when they spoke about engineers as “agents of technological humanism”, or with the referral to engineers as “barbarians”

Barry (2012). In fact, empathy (or the lack of empathy) of civil engineers was frequently mentioned by interviewees when they were discussing the importance of transversal skills for the profession.

One of the participants mentioned that civil engineering schools are starting to acknowledge the importance of these transversal skills, even though introducing them in programmes is not straightforward due to the difficulty in teaching them. In his own words:

> "Communication, cultural awareness, an attitude of learning, and so on... For me, these are base competences that should be introduced in the curriculum. But many engineering faculties, civil engineering faculties, are kind of acknowledging this, right? They say this: we need to work on our soft factors, and things like that. But I think it's much more fundamental than just having a few classes. I think this needs to become much more inherent and it might also change then the type of students that take civil engineering. So, it's because you will be expected to do more than just say yes or no."

As the quotation reflects, from the perspective of the interviewee, training in social competences would involve educating students with a higher capability of critical thinking (where they not only have to "say yes or no"). Besides from critical thinking, communication seems to be regarded by many as an essential skill. In the context of societal aspects, various interviewees highlighted that being able to communicate to non-engineer parties, such as citizens, was essential such as for ensuring acceptance of projects by local communities.

Nonetheless, the level of importance of these skills was regarded differently in different countries with different socio-economic and political contexts. One of the participants explained this as follows:

> "In mainland China, the government will plan all the things. And once they have planned that, 'okay, we are going to develop a certain area'. The engineers will go there and construct. In Hong Kong now we have similar things, but with a minor difference: let's say the government will still plan the things, but we have public consultations. So, some engineers will have to be trained to,... explain to the public and also when they plan the project, they need to consider the, well, 'does this have any adverse effect?' because if there is a lot of complaints in the neighbourhood, sooner or later, you will get yourself into trouble because there will be difficulties to proceed with the project.
>
> So, I think things are different in terms of the education, as well as when they come to work because of the different backgrounds."

It can be observed that this professor felt that there was a geographical component to the education of civil engineers dictated to certain extent by the political and socio-economic situation of a project. In fact, this issue was reflected in the difference of responses by different interviewees, as will be explained in more detail in the following section.

Finally, in addition to transversal skills, there was diversity in terms of what exact knowledge areas are needed by engineers. For instance, several participants talked about the need for understanding the context where civil engineering works are. For instance, a professor indicated what follows:

> "You would hope that we trained our civil engineers in a way that allows them to be cognizant of all of these different stakeholders and able to translate the science and technical stuff into, into an application. I mean, I see that's where engineering in general sits is in. You've got a scientist and then you've got a policy person or a, you know, a user and an engineer is kind of a bridge between those two because it's founded... you know, what we do is founded in fundamental physical science. Water flows down here, and we know how fast it goes, but

> then how do you translate that into something that minimizes impacts or optimizes outcomes is where the engineer sits?
>
> And so I would like to think engineers are doing... well, have the role of bridging those different stakeholders, but I don’t know how well we do that.”

This statement reflects an uncertainty regarding what exactly the role of a civil engineer is and the extent to which civil engineers are working more closely to society.

4.3.3. Professor’s profile

Some interviewees mentioned that they perceive that age and field of specialisation of professors are usually factors that determine how open they are to changes and to integrating more contemporary issues to their subjects or the programme in general. In particular, participants in the interviews said that older professors usually resisted more to changes, and that professors from fields such as material sciences (such as concrete), structural analysis or geotechnical engineering were not often interested in social aspects.

Nonetheless, as for age, no particular pattern was observed among the participants, and both professors in early and later stages agreed to take part in the interviews. This question will be analysed in more detail for the case of Spain (Chapter 5) with the support of quantitative data from the survey.

As for the specialisation field, there were a few participants from the three above-mentioned subdisciplines who showed an interest in the social sciences and humanities and their integration in the programmes. Despite this, they recognised that there were added complexities in finding coherent ways through which to integrate these contents in their subjects.

Related to this issue, it needs to be said that some interviewees talked about the importance of finding the adequate person to teach such social issues. A professor mentioned the fact that it is more significant to find a professor with the adequate attitude than necessarily a professor who is a social scientist:

> “Both [civil engineers and social scientists] can be horribly bad teaching the social aspects to engineering students. But I also think that both can be really good. So, the key thing here is to find the right people who have the right background and perhaps also have the right mindset.”

In addition to the specific mindset of the professor teaching these subjects, many interviewees highlighted that it is of vital importance that these topics are taught within an engineering context rather than from a social science perspective:

> “I think often you need to prime students by giving them this sort of information from an engineering perspective, because I think if you just go straight into like getting social scientists or other non-engineers to present, it can be,... I think it can be too much. Like... too different. And I think there is some value in it being translated into a format that engineers might find comfortable. So,... but in some cases, I think there’s a lot of value from social scientists, especially if it’s a smaller setting so that the nuances can be explored and translated and, and considered.”

In fact, the above contradicts to some extent the perceived benefits of students taking subjects in other faculties, which will be explained in subsequent sections. Among the participants that talked about the background of the professor teaching these issues, there was a common agreement on the fact that having “professors from outside” may lead students to think that what they are teaching is not as important as the other contents.

> "And it's not an easy fix to just hire a lot of sociologists or political scientists or psychologists, in order to teach engineering students. You actually need to know a bit about their field. Otherwise it becomes sort of like abstract often, or it becomes not relevant for them basically. And then it also becomes quite uninteresting for them. And they don't know really what this is about or what it's for. And that might also have quite negative consequences."

On top of the barriers by students' attitudes, a few interviewees also talked about the different cultures of schools and universities, which may cause difficulties for professors "from outside" who have the adequate mindset as described above. This phenomenon was described as follows:

> "There is also a lot of different sort of cultures and modes of education in different departments. So if you come from the outside, it's easy to do their own thing, with air quotes here, I mean to violate different sorts of norms they have. So that is another reason for why it's good to have teachers who are actually at the departments to do at least some of the teaching in these fields, because they know the students, they interact with them all the time. And they know how to approach them in the best possible way."

4.3.4. Integrating mechanisms

As it was explained in Section 2.2.2, curricula of several universities around the world were analysed by comparing different indicators. The findings of this study are shown as a graph in Figure 4.2. Unless statec … and huma … ject, the ye …

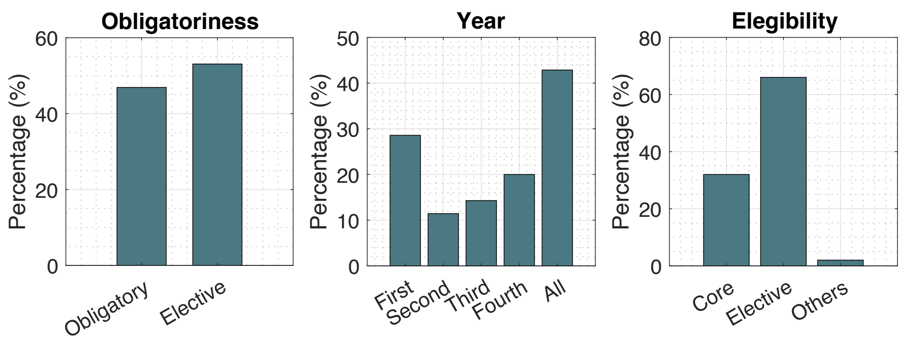

Figure 4.2. Statistics concerning the indicators analysed in relation to obligatoriness, year and eligibility

First, it can be seen that with regard to the year in which the subject is taught, there are two main trends. On the one hand, approximately 29% of programmes include social sciences and humanities subjects in the first year, whereas more than 40% include them in the second year or later. The proportion of programmes in which these subjects are included solely in the second, third, or fourth year is relatively low.

Secondly, as for the obligatoriness of social sciences and humanities subjects, there is no substantial difference between programmes that make it compulsory to take social sciences and humanities subjects and those that make it optional. Note that these results do not include programmes in which no social sciences and humanities subject is available. Apart from discerning between whether the student needs to take the subject or not, it is also possible to compare whether this is a core or optional subject. In this case, more than 60% of the programmes allow students to choose what social sciences and humanities subject to take, whereas around 35% offer it as a core subject that cannot be changed.

Figure 4.3 shows the percentage of credits in the civil engineering undergraduate programmes from each university that correspond to social sciences and humanities subjects. Figure 4.3a shows the results obtained from all the universities analysed; Figure 4.3b shows the proportion of credits corresponding to the cases in which they are obligatory, and Figure 4.3c shows the results for those curricula that have social sciences and humanities subjects specifically related to the field of civil engineering. In the three graphs, the red vertical line shows the mean percentage of credits corresponding to each case.

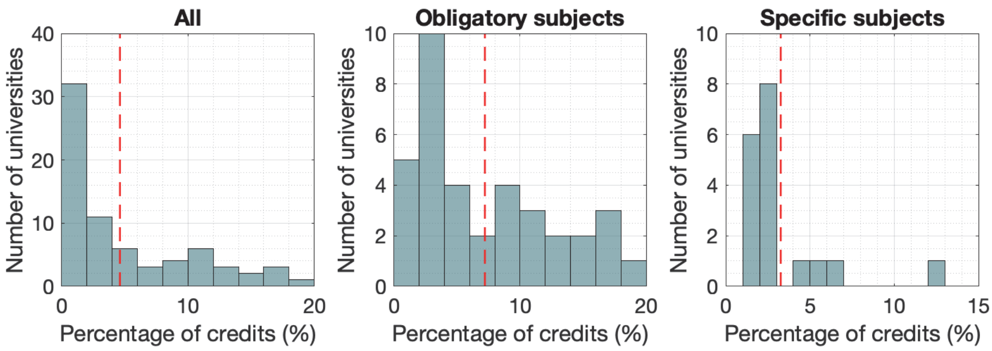

Figure 4.3. Statistics of the indicators analysed in relation to the proportion of credits. The mean percentage of credits is shown by a red dotted line.

It can be observed that there is a decreasing trend in all the graphs. This means that there are fewer universities with a higher number of credits allocated to social sciences and humanities. Regarding the obligatoriness of social sciences and humanities subjects, a total of 35 programmes set them as obligatory, and they have an average of 7.4% of the credits in their programmes. Only 18 of the faculties considered in this study incorporate specific social sciences and humanities subjects that relate to civil engineering, with these subjects accounting for 3% of total programme credits on average.

The issue of the obligatoriness of these topics, and the year in which they are introduced was discussed by several interviewees. Regarding obligatoriness, one of the interviewees, who is professor in the humanitarian engineering specialisation, argued that even though such specialisation is something that can be chosen by students following their personal interests, training engineers with the mindset of the societal context is particularly relevant. More specifically, this participant mentioned the following:

> “In terms of our engineering education and the integration of these broader concerns, it needs to be compulsory for sure. In an ideal world, it would be a theme that runs through everything that we do. In practice, that’s unlikely to happen. And, therefore, we do need explicit courses that deal with these issues so that we can at least make sure that students are exposed to some of it.”

The same interviewee acknowledged that the effectiveness of such courses may also be hindered by the fact that their relative importance is perceived as being lower than other more traditional engineering courses. She said:

> “The risk of that is that then students see it as an add-on and it’s just, ‘Oh yeah, there’s the sustainable course’. Like, whereas, you know, we’ve had students say ‘We don’t talk about sustainability in any other course, other than sustainable infrastructure’. And that’s not the way it should be, but I don’t think you’re ever going to get someone who teaches, you know, structural analysis, to really be passionate about giving up teaching something about structural dynamics at the expense of, ‘Hey, this is how you think about people’. And, some courses fit better in this sort of idea. Hopefully, you have the people teaching those courses that have that

world view so that you can ensure that it is integrated, but there's so many pressures on the curriculum that it's really hard to teach everything that you're passionate about."

The opinion that courses solely focused on social aspects may be seen as something different from the core curriculum was shared by several participants. In fact, one of the interviewees was currently working at the same faculty where he had done his undergraduate studies, and acknowledged that that was what he had felt:

> "In my first year of my undergraduate course, I had something like philosophy or something like that. And that was the first time that I had contact with that. They were not connected to the others. And I don't think it was the best solution, but it was one approach that worked somehow. But my view is that teaching would be more effective if it was connected to the other disciplines in not only in the first years of the students' life, but during the whole degree."

The same interviewee talked about the fact that he had appreciated the value of those subjects once he had already finished his degree.

The way to harmonise the need for introducing specific social sciences and humanities subjects and avoiding that they are perceived as an "extra" in the curriculum may be what a few interviewees proposed as a "compulsory introductory course on socio-technical systems, basically dealing with the need to understand social issues relevant to civil engineers". However, not all faculties have the resources, the structures or the adequate professors to teach such subjects. Concerning this, a few interviewees mentioned that students being able to take courses from other faculties could be positive in order to complement some of the needs in the civil engineering programmes, as the following participant explained:

> "The civil engineering undergraduate curriculum,... it's a very, very technical, but has become less over the years because of the increase, the need to train students to think beyond a very narrow discipline. So, we have had to make almost one third of the original curriculum space for so-called general education modules. So these cover things, modules in the social sciences or business or computer science, things like that. So some of them are compulsory, some of them are, most of them actually are electives. Students select from a basket of modules offered by other faculties."

However, civil engineering schools which belong to universities that do not have social sciences and humanities faculties may face difficulties when trying to find social sciences and humanities subjects that students can take. In addition, it needs to be noted that some universities that have engineering degrees are "technical universities", which means that all degrees that are part of the university are STEM ones.

> "The thing is that our university doesn't have social sciences,... so, I guess the closest, the pure kind of social sciences... maybe the closest we have is business school, but it's a completely different school. And we have a center for environmental policy, which again, probably there are some social scientists there, but the teaching is completely separate. So, at the undergraduate level, there is a bit of a novel lab at the, at the master level. And, we have, for example, environmental engineering with the option for business management. So, we introduce some principles of business management for it, but the students choose that as an elective. So that would be, I think, one day a week on Fridays, they would have different modules than, than the rest of the of the cohort."

Another positive aspect concerning the participation in social sciences and humanities subjects from other faculties mentioned by a few participants was that students it gave students the opportunity to study together with students from different disciplines, which is beneficial for several interpersonal skills, such as teamwork or communication.

Finally, to analyse the possible relationships between the proportion of credits allocated to social sciences and humanities and the ranking of the respective universities in the field of civil engineering, Figure 4.4 shows data on the percentage of credits corresponding to social sciences and humanities subjects together with the score for each university in the academic performance indicator. The green squared markers show programmes in which it is obligatory to take social sciences and humanities subjects, whereas the red round markers correspond to programmes in which it is not compulsory to take them. Note, furthermore, that programmes not offering social sciences and humanities subjects are also represented. They appear in the bottom line because the corresponding percentage of social sciences and humanities credits is equal to zero. A dashed line has been plotted along the x and the y-axes to mark the mean of the corresponding variables represented on each axis. Besides, the number of markers of each colour located in each quadrant have been written in the corners of the chart.

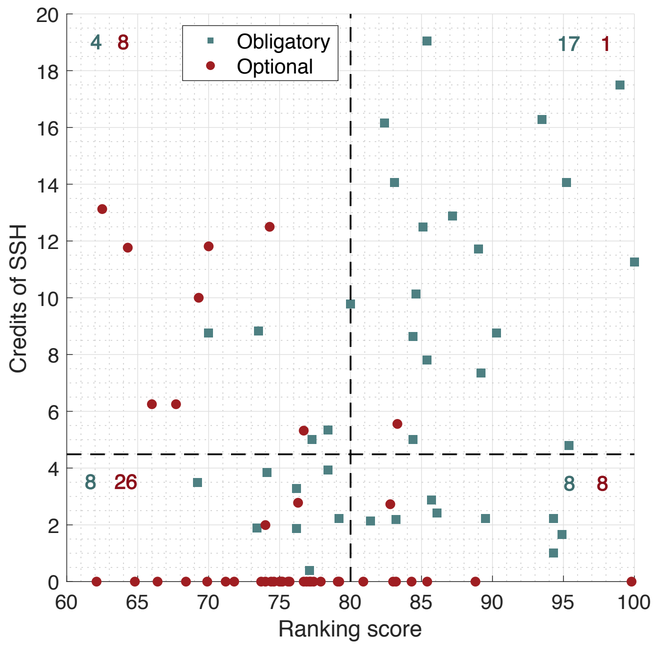

Figure 4.4. Four quadrant chart of the credits allocated to courses with a primary focus on social sciences and humanities of each program, and respective academic ranking score

The graph shows that in the top right quadrant there is a higher number of markers corresponding to university programmes that have obligatory social sciences and humanities subjects in their syllabuses. On the contrary, in the bottom left quadrant, there is a more significant proportion of markers belonging to programmes without obligatory social sciences and humanities in their curricula. The other two quadrants show similar proportions of the two typologies.

This shows that there is a high correlation between the ranking score in terms of academic indicators and the proportion of social sciences and humanities credits that are included in the programmes. There are multiple, complex links between a programme’s syllabus and its faculty ranking, because this affects both the inputs and outcomes directly and creates many positive and negative externalities. Figure 4.4 provides evidence that the relationship exists between the two variables considered, and that an efficient allocation of social sciences and humanities topics and subjects in programmes may be considered as a response to an effective improvement of academic outcomes.

Having said this, it is also necessary to examine the specific contents of the social sciences and humanities credits analysed above. First, one relevant aspect to emphasise is that notably wide diversity exists regarding which social sciences and humanities subfields are included in each programme. One element that adds to this variety is the fact that some universities offer a vast range of optional subjects, that are either provided by the engineering faculty or social sciences and humanities faculties at the same university.

With regard to the subjects that have social sciences and humanities as their primary focus, two main trends were observed in terms of how social sciences and humanities were incorporated. On the one hand, among the degrees that offered social sciences and humanities subjects, some had courses in the social sciences and humanities area that were not specific to civil engineering. Generally, these faculties offered the students the possibility of choosing one or more subjects from other faculties at the same university. It should be mentioned that the variety of possible choices for students is rather wide in this case.

On the other hand, the remaining universities analysed did offer social sciences and humanities courses that were specific to civil engineering. Two subjects that were relatively common in these cases were project management and economics for civil engineering. The other subjects that were found included the following areas: history of civil engineering, health and safety, ethical and/or legal considerations in projects, culture, and humanitarian engineering.

In addition to the above, one common subject found in several universities was referred to as “Engineering in society”. This subject belonged solely to the civil engineering degree in some cases, and in others, it was a general course to be taken by students from different engineering branches.

As for courses that did not have a primary social focus, there were two courses that proved to be relatively common for all faculties. On the one hand, courses connected to engineering sustainability were identified. These were courses that included conceptual aspects of sustainability in their syllabuses, as well as elements related to environmental impacts. Even though the social pillar of sustainability was not mentioned, it could be included in the course. On the other hand, there were courses that dealt with engineering design which were mainly based on students designing a project. In these cases, there was the possibility of incorporating a wide range of social issues, even though the project could also be purely focused on technical civil engineering aspects.

Finally, some faculties offered either obligatory or optional courses, mainly focussed on transferable skills. Overall, the courses found in this area related to communication, both written and spoken.

4.4. Willingness to change

This section examines the elements that influence the willingness of the various stakeholders involved when it comes to integrating social aspects in programmes. In particular, barriers that professors, students and civil engineering schools encounter are described.

Participants mentioned various factors that they considered to be barriers they encountered when trying to integrate social concepts in their subjects or in the civil engineering programmes. Most of these factors were directly or indirectly related to professors, but some aspects that have to do with students were also mentioned by interviewees.

There were five main factors that were mentioned by participants as barriers encountered when trying to integrate social concepts in their subjects or in the civil engineering programmes related to professors: resistance to change, time, and assessment methods.

First, as for resistance to change, this is an element that has been examined in the past by some authors. This phenomenon has been detected in multiple contexts, such as Spain (Aznar-Díaz et al., 2020), Germany (Lust et al., 2019), or Rumania (Neculau et al., 1995).

Second, time was mentioned by almost all interviewees when discussing the disadvantages of integrating social sciences and humanities contents in civil engineering programmes. This was seen from two perspectives: professors’ time and time allocated to subjects.

On the one hand, multiple interviewees talked about their need to prioritise time for research instead of preparing their classes. Several faculty members described how they are mostly evaluated through publications rather than their performance when teaching and the adequacy of the taught contents. The issue of the importance of publishing will be examined in more detail in the next chapter.

On the other hand, time allocated to subjects was a factor that was very frequently mentioned by interviewees as a constraint to integrating social issues in their subjects and in the programmes. One participant declared the following:

> “So for example, I teach water resources engineering. I would love to have a lecture on indigenous views of water in Australia and indigenous water management techniques. And yet I can’t even teach all the stuff I need to teach about, you know, flood hydrology. As opposed, you know, as, as dictated in Australian rainfall and runoff, the design guidelines. So it’s hard to make that sacrifice. There’s possibly, you know, we’ve all gone, you know, all our courses have been online this last term because of COVID. Well, maybe we can start to move some of that stuff online and then talk about some of the more interesting stuff.”

As it can be observed, this professor was willing to integrate social issues in her water resources course, but considered that she did not have enough time already for the basic concepts, and would not be able to include “extra” aspects.

In spite of the above, one participant that had led the restructuring of the civil engineering programme in their faculty, mentioned that there seemed to be repeated content in the programmes. When speaking about including new issues in the subjects, this interviewee described the following situation:

> “I think it [including new issues in the subjects] is very difficult because they [professors] will always say, as the staff said to me, ‘we have 10,000 things we need to teach the students. So if you add however many things in social sciences into the curriculum, what do we take out?’. And I think if they’re not prepared to address that problem, then they are not likely to move because they will always see that the curriculum is completely full.
>
> I found when I looked at the curriculum, of our previous degrees, I found huge amounts of duplication and, irrelevant stuff in there. I went through every line of the curriculum, of the syllabus with the staff and said, well, why is this here? Why is it in the first year and why is it, you know, why are we doing?”

The third barrier found was related to assessment methods. A few interviewees talked about the added difficulty of objectively evaluating knowledge in social contents in comparison to engineering contents. The latter tend to involve calculations, results are often quantitative and can be evaluated more easily and more quickly. Nevertheless, social contents do not always require numeric results, and their assessment needs to be done on the basis of written responses. When talking about evaluating written essays, a transportation professor explained the following:

> “It takes more time and they’re used to very, very concrete marking and so... you know, essay

work, more qualitative work, is inherently more subjective in the marking. Even if you have a rubric, you know, your rubrics give this kind of veneer of objectivism to what is still essentially at its hardest subject, the process. So, that also kind of freaks students out a little bit. And you get a little bit more pushback on that. And it takes more time, so that's a bit of a pain, but, I don't mind it."

As it can be seen, in addition to objectivity, time was also a drawback given the higher amount of time needed to grade students' responses. The same interviewee continued to explain that he was forced to do it due to the nature of his students:

> "Also, I'm kind of forced to do it because I have a lot of planning students in my graduate courses and they hate problem sets and they complain about the problem set. So I basically get,... you know, each student will complain about the other type of homework assignment.
>
> So it helps to kind of keep me in the middle, trying to get half the students complaining about each ones. It would be harder if I didn't have the planning students kind of pushing for it and, also voicing the other side. Right? So if a student speaks up in class and complains about the writing component or its subjectivity or qualitative component or something like that, it helps a lot to have a different student voice, the opposite opinion in the room, so students can understand, 'Oh, well, you know, there's different perspective in this course, it's actually kind of splitting the difference'."

This professor taught in a class with students from an engineering background and a social science background, so he was forced to find a compromise between the two types of assessment. Nonetheless, he acknowledged that if the nature of his students was not interdisciplinary, he would probably use mostly purely engineering questions in the evaluation activities.

Having said this, regarding the barriers by students, most comments kept a relationship with the fact that they may tend to see social aspects as the easy part of the programme. In itself, this does may not necessarily have negative effects on the learning journey. However, interviewees said that this led to students not engaging properly with the material, and therefore not reaching the expected outcomes of the course.

4.5. Propitiousness for change

While the legal system of universities may be prepared to make changes in the curricula such as the integration of social aspects and professors may be willing and prepared to do so, there are some external factors that could make the situation more advantageous.

In particular, data from the interviews reflected that there are three main factors that help making the overall environment more propitious for integrating relevant contents from the social sciences and humanities in civil engineering university subjects and programmes.

The first factor is related to the characteristics of the country where the civil engineering school is located. The status of the profession and of education in different contexts influence indirectly the way in which the education of civil engineers is made. Secondly, the perceptions towards different disciplines that exist among academics and professionals may make it difficult to integrate engineering concepts with social sciences concepts. Thirdly, the environment within civil engineering schools, such as the relationships between professors, could create more positive situations for the inclusion of social aspects in programmes.

4.5.1. Country context

The specific contexts of the countries that were analysed were examined in detail to detect possible regions where the overall context of the country (technological progress, lack of infrastructure,...) may be rendering the situation in civil engineering schools more propitious for change.

Among all the contacted professors, the region where the least number of positive responses was received was Asia. In fact, one professor commented on the following:

> “We have quite a large international student populations. I teach third year, so they’ve already done, you know, two years of courses in English, but I do think that sometimes,... we have a large demographic of students from China in Australia that they’re all good. They’re always going to do a lot better in courses where it’s very mathematical because that’s as an international language. Whereas once you start getting into some of these more, people discussions, it’s a little harder. The language becomes more important and it’s very hard to assess.”

Nonetheless, having said this, the country of the civil engineering school was not found to be a determining factor in the way in which the introduction of social sciences and humanities is perceived. In fact, the character of the university was found to be a more relevant variable. For instance, this was seen in the two civil engineering schools based in UK, which in spite of belonging to the same country had two opposite institutional visions on the matter.

One interviewee from Hong Kong also mentioned the importance of the mindset of the school when trying to make these changes:

> “I think that, even though we have this 20% of free credits, we should have a more structured introduction of the social sciences into the civil engineering course. But we are very traditional school, so it is very difficult to negotiate”

4.5.2. Walls and hierarchies between disciplines

The existence of strict borders between disciplines (in this case, between civil engineering and social sciences and humanities) was seen as an element that makes it difficult to bring together the two of them, not only because of their inherent differences, but also due to the perceptions arising from such disciplinary perspective.

In fact, a few different participants talked about the feeling of having to protect one’s discipline in front of scientists from other disciplines.

> “I feel that at the university, people, social scientists and engineers are very protective of their discipline. And so··· when an engineer wants to be a social scientist, or to tread over into that area, the social scientist doesn’t think that they’re using the right approach or they’re using the right qualitative or mixed methods or even quantitative methods. And then likewise, if a social scientist, tries to do work in an engineering field, the civil engineer does not think that their approaches are correct.”

In addition to boundaries between the two disciplines, the responses of some participants reflected a split between the perceived hierarchy level of social sciences and humanities and civil engineering. More specifically, some interviewees referred to the social sciences and humanities as *soft sciences*, whereas they called the more technical part of civil engineering as a *hard science*. This sometimes translated directly into *easy* vs *difficult* in words of some of interviewees.

As it can be seen, the perceived difference is hierarchical. In fact, one of the interviewees specifically mentioned that there exists this very common perception in the country of her university (in the United States), where STEM fields are at a superior position than social sciences and humanities fields. This phenomenon may be reflected, for instance, in the funding for research grants, where more funding is sometimes allocated to STEM projects.

4.5.3. Teaching and research environments

There were several factors related to the environment at the civil engineering schools that could render the setting more propitious to make changes in the contents taught and, in particular, to introduce the specific issues that are being considered in this dissertation, namely social issues. There were three elements that were commonly indicated by interviewees which will be presented next in more detail: physical conditions of classes, interpersonal conditions in the school, and the divided importance given to education and research.

First, conditions of classes and students' groups such as the number of students in class or their nationality were mentioned by professors. Nationality of students was discussed above to emphasise the difficulties that having international students may cause in class debates and written essays. Regarding the number of students, one participant mentioned the following:

> ''We have really, really large class course numbers. I have 400, 500 students in water-resistance engineering, so the ability to have nuanced discussions about things is really hard.''

As it can be seen, this interviewee associated teaching about social aspects with the need to have discussions in class, which is something that was also indicated by other participants. A few professors talked as well about assessing written essays (which are more typical in non-engineering contents, as was explained before), and the fact that higher number of students made the task of grading more strenuous.

Second, on top of the conditions in class, personal relationships between professors were found to be an important element that could encourage conversations from which motivation to make positive changes in curricula would come out.

In particular, one participant talked about how the culture of work in the department had changed, and at present there was less time allocated by professors to interact with other professors. This caused, from the perspective of this interviewee, to have less discussions regarding societal issues. He described this as follows:

> ''In the good old days we had, the staff, lunch together. Normally there would be more than 10 of us. That was before our department moved to another very remote area. Now we cannot have the Chinese tea for that. So that's how we used to have lunch together and then we would have discussions, but now seldom we get in touch with the things on the society. We would talk about the news. But these days things get more and more remote because now we are in a single building a little bit far from the main campus. So going to lunch is a little bit further away. So, if you want to have lunch, you need to walk quite a distance. And during the term time we don't have luxury to have two hours lunch. So, nobody goes to the Chinese tea anymore. And then there won't be a lot of discussions of what's happening around or even to something related to the society.''

In the case of this participant, relationships between professors had deteriorated due to structural changes in the campus. Nonetheless, participants from other institutions also indicated the feeling of not being able to dedicate so much time to personal relations, mostly due to the high number of commitments in terms of research and education.

Third, data from the interviews illustrated the differences in professorship systems in different institutions and regions worldwide. In particular, a relevant issue that was reflected by participants from the Australian civil engineering school is that they have two profiles of professors, one that is teaching oriented and another that is focused on research. Professors from this institution discussed the benefits of such approach, which allowed them to focus most of their time to one of the two areas and, therefore, gave them more time to think about changes to be made in the curricula in the case of the education-centred profiles.

4.6. Summary

This chapter examined the situation of implementation of social sciences and humanities in civil engineering programmes from a global perspective. For the analysis, a triangular approach was taken. In it, information from field interviews and bibliographic research were combined in order to better understand the current role of social sciences and humanities in universities and to propose methodologies through which social topics can be introduced in formal HE programs. Such analyses helped also to reinforce the necessity for consolidating a civil engineering body of knowledge that is comprised both of technological and social sciences and humanities technical knowledge.

The analysis of the status of integration of such content was done considering four pillars: ability, willingness, preparedness and propitiousness to integrate social aspects.

First, results showed the importance of the role of accreditation systems and professional associations in shaping the education of civil engineers. Even though these bodies may support and help to move forward certain changes, they can also act as slowing forces.

Second, a wide variety of mechanisms for integrating social aspects in civil engineering education was observed. Among participants, there was no common agreement as to how social contents should be incorporated into curricula. However, most of the interviewees subscribed the fact that it would be interesting to teach general social content in the first years of the programme, and more specific knowledge in the last years.

Finally, one of the most significant barriers that was mentioned by participants is resources. This includes a broad spectrum of resource types. Three main elements may be distinguished. The first one is the time needed for preparing new content to be taught; the second issue is the large amount of contents in the courses, and the consequent lack of flexibility to include new aspects without removing some of the essentials; the third aspect is the lack of training (or the perception of lacking enough expertise), in some cases, of some professors to teach social contents.

5

The “social” in civil engineering education in Spain

The results presented in this chapter are currently under preparation for publication in a journal.

5.1. Introduction

In the previous chapter, the status of civil engineering education at universities around the world was examined. This chapter adopts a closer perspective by focusing on Spanish civil engineering schools. It analyses the enablers and barriers to the integration of social aspects in civil engineering programmes. As it was hinted in the introduction of this thesis, the evolution of engineering education in various regions of the world has shown variations due to the socioeconomic and political context at different moments through history.

In Spain, the origin of the civil engineering profession is linked to Agustín de Betancourt (1758 –1824), who founded and managed the Spanish Corps of Civil Engineers as well as the first civil engineering school in Spain (1802), which was based in Madrid. Back then, the studies had a duration of two years. In the first year, students were taught mechanics, hydraulics, descriptive geometry, earth and vault thrusts and drawing; in the second year, they were taught about construction materials, machinery used in construction, bridge construction, and the construction of roads and navigation and river channels. Since then, there have been changes in the study plans have changed several times.

Since the first civil engineering school was established, the number of civil engineering schools in Spain gradually increased. Among the existing schools, there is the civil engineering school located in Barcelona, the Technical University of Catalonia, which was founded in 1973. Its study plan until the academic year 2009-2010 was the 1964-1975 plan, which was modified in 1983. This plan consisted of four years that were common to all civil engineering students, and then two years focused on specialisation. The specialisation areas were foundations and structures, transportation, urban and land planning, and hydraulics and energy. This plan changed after the Bologna process, and the new one was first carried out in the academic year 2010-2011. Recently, a new plan was presented, the one starting during the academic year 2021-2021.

In this context of changing trends and needs, this chapter combines the data collected from surveys and interviewees working in Spanish faculties with the objective of better understanding the barriers and catalysers existing in the process of implementation of social aspects in the education of civil engineers, the perceptions in the civil engineering academia towards social aspects, and other related subjects.

For this, this chapter is comprised of four main sections besides the introduction and the summary in the end. In particular, the findings are grouped into four themes that describe enablers and barriers existing in the process of integrating contents from the social sciences and humanities in civil engineering programmes[1]. These themes are ability, willingness, preparedness, and propitiousness and are represented in Figure 5.1. These four groups of issues are particularly relevant for the first two research questions presented in Section 1: (1) what areas within the social sciences and humanities are considered as most relevant for civil engineering in the literature and among relevant stakeholders?, and (2) how are the social dimensions of civil engineering perceived in civil engineering academia, and what are the barriers and catalysers for incorporating social aspects in the education of civil engineers?

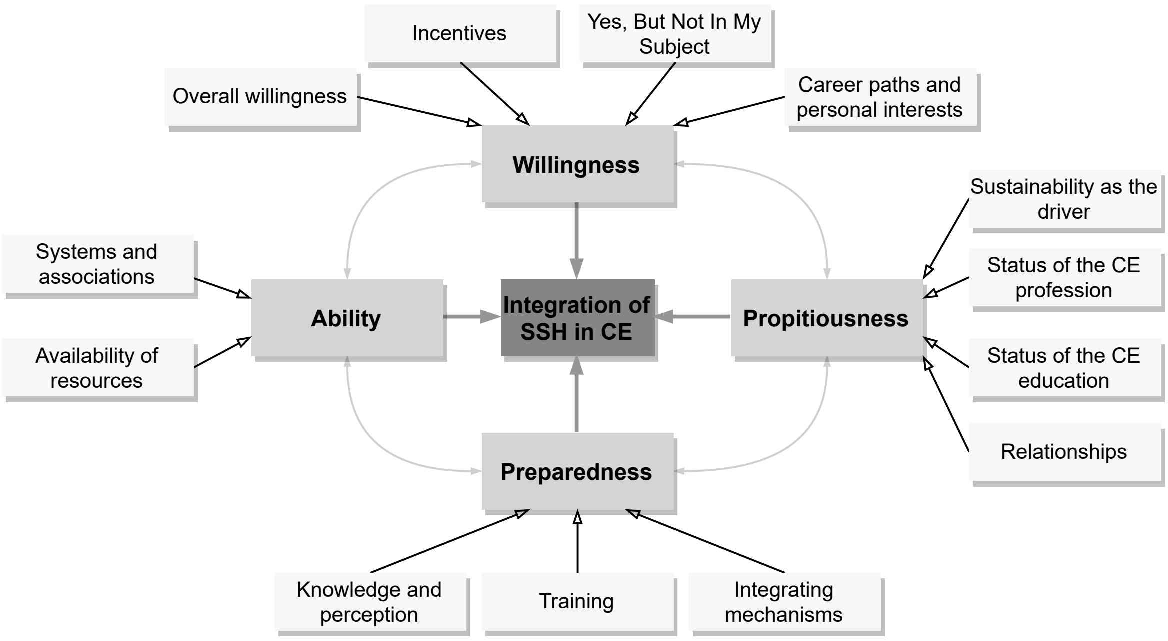

Figure 5.1. Themes analysed of the GT-based model for the Spanish case

First, the ability refers to the ability to make changes by different actors in the academic environment. For instance, regulations or certain rules may make it more difficult to integrate new concepts in programs or specific subjects. Another example would be that one of professors that are not the coordinators of a subject and do not have the capability of integrating new concepts.

Then, preparedness refers to the state of being prepared for making the necessary changes addressed in this study. A related example would be the lack of training that some professors felt and that hindered their capability of integrating social issues in their subjects. Individuals may or may not be willing to introduce or adopt changes in their academic activities even when they are able and trained for it. This is what is included in the theme willingness.

Finally, propitiousness refers to the issue of whether the environment is favourable or not to changes. It could be that the (academic) environment is not suitable or advantageous for this specific purpose. Also, the global situation may be more or less favourable for integrating social issues. In the present case, this was reflected in the state of the civil engineering profession and education.

[1]Such groups were defined during the qualitative analysis process.

The factors included in each of these themes are explained in further detail in the following sections.

5.2. Ability to integrate social aspects

According to the collected data, the ability to integrate relevant content from the social sciences and humanities in the civil engineering programmes is influenced by two principal factors. On the one hand, the existence of regulatory frameworks and organisations may affect (either positively or negatively) the process of incorporating these issues. On the other hand, the availability of resources by professors, research groups and departments seems to also be determining the ability to change in this area. This is described in more detail below.

5.2.1. Role of systems and associations

The university system: static and research-focused

The first barrier to the integration of content from the social sciences and humanities in civil engineering education that was found was the structure and organisation of the university system. First of all, data from the interviews showed that there is a contrast between the dynamism of technological development and the rhythm at which these changes are being introduced in the engineering programs. As some participants pointed out, “many professors are still teaching the same that they taught 30 years ago”.

Nonetheless, it is not only the renovation of the teaching content that seems to be static but the whole system itself. One participant highlighted the rigidity and slowness of the system as follows:

> “Technology is constantly changing, and we need to teach young people to navigate these changes. The educative system does not work well for that. We have an educative system that accredits educational programmes through the ANECA[2]. Anyone has to certify their degrees for them to be official. It’s a slow, rigid process. It is a process to allow for little changes in reality. We need a process that is much more flexible, much less regulated by the Administration, and much more regulated by the social reality. Every school should teach what they consider convenient, and they should focus their training on the aspects that they consider the most interesting.”

The quotation above reflects certain pessimism with respect to the current system, mostly related to the rapidity of changes. Besides the speed at which changes are implemented in HE, most participants talked about the professorship system in universities, including the types of positions that professors have throughout their careers and the emphasis that is given to research.

Regarding the former, a great majority of participants mentioned, in more or less detail, the type of contracts in university (associate professor, adjunct professor, full professor...) and the complexity of consolidating a career. When they did, they gave a pessimistic vision about it and how it has affected the university system.

In relation to contracts and types of professorship positions, participants mentioned the “*sexenios*”, six-year periods after which professors need to prove the activities that they have carried out. Most of the activities that they need to prove are, in fact, related to research, which is again connected with the emphasis given to research. Apart from these six-year periods, there are also the professors’ accreditations, in which professors are evaluated according to their research activities and some teaching activities in order to be able to access a certain professorship position. A greater emphasis is given to research in order to obtain each *sexenios*. With reference to this, an interviewee argued that it is more

[2] From the Spanish “*Agencia Nacional de Evaluación de la Calidad y Acreditación*”, meaning National Agency for Quality Assessment and Accreditation

difficult to measure the results of teaching quantitatively compared to those of research:

> "Well, it is very difficult. On the subject of teacher evaluation, evaluation is very complicated. You know that professors have a kind of exam every five or six years. People evaluate what you have done. So, in research, this is relatively easy, because the product that you obtain is a product that you can read, that you can evaluate, and that other people has evaluated. But it is very difficult to monitor teaching, there are some surveys to students, but it is difficult to evaluate what a professor does."

Concerning the issue of the emphasis that is given to research, most interviewees highlighted the emphasis that is given to research in their respective university systems (as some mentioned, it is a "publish or perish system"). Such emphasis affects other elements of this study, but mostly the intervening condition "resources", as the pressure that professors feel for publishing makes them invest a great amount of time on research rather than on trying to make their subjects up to date or integrate new concepts. Besides, those that tried to publish in interdisciplinary areas between civil engineering and other social sciences and humanities disciplines acknowledged that it was usually more difficult, and one publication would frequently need more time for preparation.

The various elements defining the university system described above made some of the participants believe that they would only be able to make changes and influence decision-making processes if they had already a consolidated career in their institution. Firstly, once they had a full professor position, they did not have to worry so much about publishing and could dedicate some more time to other activities. Secondly, some participants felt that decision-making processes were not transparent enough and that they did not really have a voice when it came to participating in such processes. It was when they were part of specific committees or bigger research groups that they had the opportunity of participating in such processes.

Thirdly, given that young academicians do not usually have a consolidated career, they focus on researching and publishing as much as possible in highly specialised fields. This was not true for a couple of participants, who admitted that they had decided to broaden up their research into more interdisciplinary areas, even when this meant publishing less and not obtaining their accreditations as fast. One of them said the following:

> "I am not very concerned about research and about the six-year terms. Now I have two sexenios, and I am currently asking for the third one, but I have not worried about it. I have been working in a private company and have been publishing things because I wanted to. I haven't wanted to fit myself into this mould. I was already a tenured lecturer, and I did not want to get into this dynamic. Honestly, I don't do these things for the six-year term. I want to enjoy what I do."

In this case, even though the interviewee said that he had made the decision consciously of its consequences, his alternative job in a company gave him certain security in terms of employment[3].

In brief, as one participant described, "to dismantle the system, you need to be at the top of the system", referring to the fact that most changes at university required to be in high positions, including the integration of social aspects in civil engineering education.

Professional associations and their link to schools

Civil engineering professional associations (the *Colegios de Ingenieros de Caminos, Canales y Puer-*

[3]There is a specific position in the context of universities in Spain that allows working in a company while having some working hours at university. It is the "*professor asociado*".

tos) were mentioned by a few participants. Participants raised the issue of the fact that these associations seem to be aware of the need for civil engineers to understand more about social sciences and humanities areas. Also, they have certain power within the industry and they also have knowledge about the profession’s situation and present concerns. Therefore, the role that these associations could have in producing changes in civil engineering education could be important. One interviewee described this as follows:

> “I think that one of the things that might be good, I do not know, is that the *Colegio* has a say here in the school. I am not registered in the *Colegio*, but I know that it handles projects that are carried out in the region. That is, they know about them, and they can give you orientations on what the specific issues are, and this depends a lot on those of the country’s region. [...] Then... I do not know. I believe that there are always organisations that have a little more knowledge about these local issues. With questions like ‘What are the needs?’ ‘How do we adapt to these needs?”’

Nevertheless, at the same time, data from the interviews showed that the connections that these associations currently have with civil engineering schools do not appear to be strong enough, hence diminishing their potential. As one participant put it:

> “It seems to me that it is as if the policy that the *Colegio* has is to try to create discussions and debates that are in fact very relevant socially, and in this sense, I do think that it is very concerned about the debates that society cares about. To me, it means clearly that they want to try to contribute their vision and be one more act of reflection on the issues that concern the public. But apart from this, citizens do not see what role it has in the school, so it gives the impression that they do not participate in it. There must be communication, obviously, but it gives the impression that apart from the topics that they deal with on transport and mobility, there is nothing else, and they do not transmit it inwards [to the school].”

Besides the role of civil engineering associations, other interviewees also mentioned the importance of considering other stakeholders from society:

> “Well, I think that everything should be shared, and I think that it should be born of a collaboration and not just among professors. I think that, in an ideal setting, the *Colegio* should also be involved, saying what we want future engineers and engineers to be for the next 20 or 30 years. What skills they should have. For instance,... I don’t know, does he have to be collaborative? Does he have to know about leadership? About teamwork? And then, we need to transfer this vision to our studies. And this involves asking local governments too and other societal actors. And from their perspectives, we would make a curriculum that meets these needs. But it is not like that. We internally decide how we want these studies to be. I have the impression that there is not an inclusive dialogue.”

In fact, other researchers have analysed the wide range of actors that influence, to a greater or lesser extent, HE activities and services. It is the case of the studies made by Amaral and Magalhães (2002), Kettunen (2015), who mapped and characterised all the potential existing stakeholders in the context of universities.

5.2.2. Availability of resources: time and space

Resources were highlighted by the majority of the respondents as essential in the process of doing activities at university that were out of what was required to them by the university system. In particular, time and space in the curriculum were the two most predominant ones.

Time

On the one hand, regarding time, this can be seen from three different perspectives: the time that professors dedicate to their teaching and researching tasks, the time that is allocated for different subjects, and the time that students dedicate to studying and other activities.

First, as for professors' time, even if professors felt that they wanted to introduce new issues to their subjects related to the social sciences and humanities, a lack of time was a barrier for them. As one participant put it, "urgent things displace important things". This reflects a dichotomy between what the routine requires to be done and what needs to be done from an educational perspective. For instance, one participant mentioned the following:

> "You need to think that, in the end, we do not have time for anything. We start in September and finish in December. And then we start over. There is no time to stop and say... okay, what have we done? No, there is no time for that. Our framework is not prepared for that, and maybe it should. In the end, if the teaching average, teaching objectives and students' surveys are okay... then perfect. We keep on."

Apart from the time that they need to think over the teaching contents and activities, some participants reported the fact that the process of integrating this kind of content becomes richer when discussions with other professors take place. This may render the environment more propitious to this process (as will be seen in more detail in the following sections). Nonetheless, the lack of time sometimes hinders the time that professors have to have extended conversations on this topic. As one participant put it:

> "I am a person who has always spoken to everyone in the corridors and with people of any department. At the school level, there is no specific space for this kind of conversation or for meeting and chatting. All this has been lost. Everybody is very busy and in a hurry, which is not the same environment as the school of a few years ago, when I began here. (...) I feel very comfortable here, but deep down, what we did before, eating calmly and having an after-lunch conversation which was not three hours, of course, maybe it was half an hour more, or to see each other one morning and then chat for a while about things that we do, this is still done, but in another way."

It needs to be noted that the above comment concerned the lack of time, but also the structural organisation of research groups and departments as was described above. Additionally, it raised the issue of relationships between professors, which may help to create propitious environments for change.

Second, as for the time allocated to each subject, most participants did not feel that such allocation was always done proportionally to the importance of subjects but to the power that some research groups have within the institutional structure of the civil engineering school. Concerning this, some participants referred to departments as kingdoms, where there are hierarchies between groups. In general, there seems to be an agreement that those knowledge areas directly related to construction processes are the ones that have more dominance within schools because of the fact that they had high importance in the past and before the 2008 crisis, when there was the expansion of the construction industry.

Third, from the perspective of some of the participants, in the same way as it was perceived for professors' time, some participants mentioned that students seemed to lack time in general to do additional things. For instance, an interviewee described the following situation:

> "Recently, I had this conversation with a student who was complaining about her grade. It is normal that they complain. And this student seemed very hardworking and when she saw that I was listening, she explained to me that they do not have time, and because of this, they do

> not have time to learn well.”

They related students’ time to the fact that studying issues that are social in nature may require extra time for students to digest and be able to critically think about them. This issue was mostly raised by professors that were keen on teaching these topics.

Nonetheless, this contradicts to some extent the fact that some professors had the impression that social issues are easier to study and allows students to relax. In Spain, sometimes some subjects are referred to as “María” . There is no clear-cut definition of what being a subject María entails, but it is related to the subject being easy, not needing much study time, or being easily passed.

For instance, a participant talked about the subjects he had taken when he studied civil engineering in the 1980s and mentioned the following:

> “We had a subject of sociology and one of history of science. There was a third subject, I remember, an art history subject. On paper, it was very interesting, but in reality they were the Marías, to put it like that, and we did not pay too much attention to them. Our interest was in other things, but I still remember especially some master class on art history.”

The concept of these subjects is interesting to reflect how the need for this kind of topics and their relevance and interest are perceived by students. A greater understanding of these perceptions would allow seeing how these topics are best introduced in engineering degrees. Nonetheless, this is an issue that should be further researched by analysing the viewpoints of students.

Space in the curriculum

On the other hand, concerning space in the curriculum, when asked about the main inconveniences, or barriers, of the processes of integrating relevant content from the social sciences and humanities, the majority of participants mentioned the lack of free space in the curriculum.

Engineering has immensely evolved in the last decades, and new engineering topics are emerging as necessary for students to learn. As it was mentioned above, the statism of the system has not yet allowed to fully integrate these changes in the curricula. Some interviewees mentioned the difficulty in prioritising the new topics that should be included.

> “I do not think that there is anyone that opposes to including these social topics. The problem is... how do we fit it in? To what should we give priority? We have certain hours and not more. Increasingly, there are more and more regulations, broader regulations, and different topics. All this social area is now starting, but for instance, risk and quality assessment has existed for years, and it hasn’t yet fit in. There are so many topics and standards of all kinds of materials and new materials of course. All this means that subjects tend to become bigger, but the number of credits remains the same. Then, of course, you need to have priorities.”

The question of what aspects should be given priority to is indubitably important, and it is directly linked to the trade-off point between breadth and depth in civil engineering education[4]. In Chapter 4, the few references discussing this issue were reviewed and it will be discussed in more detail at the end of this chapter..

Additionally, it needs to be noted that different professor groups have a different number of credits allocated for teaching activities. Credits translate into hours of subjects. Note that such allocation is strongly related to departments, as was mentioned above. Analysis of the responses revealed that

[4] As well as in engineering education in general.

participants felt like they already could not cover all the topics with the time they had, so including even more would be difficult. Nonetheless, as a few participants pointed out, they could make changes and innovate if they wanted, but inertia left them teaching the same concepts year after year. This links the lack of time with the lack of space in the curriculum.

A participant described some of the consequences of the system described above as follows:

> “Actually, you have a subject in your department, and that subject carries a certain number of credits. And with those credits you hire x professors. Imagine now that Department X has a thousand credits and there is a modification of the study plan, and that department had been created in the eighties and it is a line of teaching that now is not so interesting anymore. So other knowledge areas appear. Well, those thousand credits in the new plan will become eight hundred, and they will have to terminate contracts. Of course, people do not want that, obviously, but if they do not terminate contracts, people need to recycle themselves to teach something else. And of course, that is not easy for a person that has been there for fifty years.”

As the intervention by the participant above shows, some subjects have been eliminated over the years, some of them because of the change in the education model due to the Bologna plan. The subjects that were mentioned that had gone through a decrease of hours, or complete elimination, were all related to social knowledge areas according to the interviewees that raised this topic. Apart from a decrease of hours and elimination, some of these subjects had gone from being compulsory to optative. Regarding the Bologna plan, some participants acknowledged that its original idea was really positive. However, the way in which it had been put to practice has raised other issues such as the lack of resources by professors to effectively carry out what they had to. Concerning the introduction of social issues under this situation of changes, an interviewee mentioned the following:

> “We are trying to incorporate more and more of these social issues into the degree, but it is getting a little more complicated, very complicated. And I would say that we are not incorporating, but on the contrary, we are increasingly cutting the role of this subject in many degrees. I mean, when I entered this school in 2005, there were many more subjects in social issues that have now been cut, or you know, whose obligatoriness has been cut. Everyone has lost obligatoriness, but in our group... it is the first activities that are being lost. There was sociology in the area of urbanism... analysing socio-urbanistic impact chains. We have been losing, so I don’t think we are gaining space; otherwise, we are losing them.”

This participant continued to explain how she thought changes should be made:

> “I think this is a bit of a school policy, to encourage some habits or others. I think it would have included maybe not doing more subjects but maybe having more participation in other subjects. If we really believe in the multidisciplinarity discourse, then subjects should give different views on a topic. But hey, this is far from the reality.”

As it can be seen this participant believed that it was not only a matter of personal motivation, but also related to the positioning and engagement of civil engineering schools and their policies. In fact, professors interviewed expressed the fact that there is a high competitivity in terms of “obtaining” subjects in the sense that professors often look as much as their knowledge areas to be included in the programmes instead of looking at their overall picture. Getting this space in the curricula is strongly related to the power that different research groups have in the school, which was already described previously. This was put as follows by one of the interviewees:

> “I guess the competition to get subjects at the university level is very high. I mean, I understand that there are many very interesting topics and that everyone watches a little through their area

> of knowledge. There are some areas of knowledge, and some are more powerful than others and these ensure that they get space for their subjects and those of us who may have less power or less capacity of influence... obviously we are the ones that are seen as small. I guess that, at the level of speech, everyone will be very interested to look after the social impacts. But, at the same time, the truth is that it is in teaching where these things are seen, and there are other issues that become more relevant.”

5.3. Preparedness to integrate social aspects

Various aspects influenced the preparedness for integrating relevant content from the social sciences and humanities in civil engineering programmes. Such preparedness can be seen from an individual perspective, which would be related to the knowledge and training that professors need (or perceive they need) to teach these aspects, and the readiness from an institutional and structural point of view. These aspects are described in the next subsections, divided in two main elements: (1) the knowledge that professors have of the social sciences and humanities, and the way in which they perceive it, and (2) possible training that they have received in social topics, and how this may affect the perceptions they have towards their ability of integrating these topics.

5.3.1. Knowledge and perception

First, analysis of the interview data revealed that there was a consistently held notion that it is difficult to define what the social sciences and humanities are. This aspect seemed to be echoed by all the informants, either directly or indirectly. This also affected what they believed would be important to include in the civil engineering programs.

In particular, some interviewees related social aspects to interpersonal skills, and in particular those skills needed to foster stakeholder participation or to communicate ideas to non-engineers. When asked about what she believed social sciences and humanities were, a participant said the following:

> “Let’s see, well, the word that comes to my mind is... maybe I am wrong... but I would say empathy. If we could not put ourselves in the place of a citizen who does not understand technical problems, calculations of budgetary limitations, optimisations, long-term solutions,... there we would not be able to build a social bond. A basis of this bond could be a dialogue with a politician, for example, through a person who is responsible for collecting complaints, the claims of society... and in turn we could explain and give a justification for what happens [referring to a civil engineering project]. I think, I think that putting ourselves in the place of someone else can help with the social science. And also... social science can help explain how things have been in the past. And they can help justify the proposals or the recommendations.”

In fact, the need for engineers to learn how to communicate with non-engineers was an issue that was mentioned frequently by the interviewees. Besides from conceiving the social sciences and humanities as a social skill, a few other professors did have more adjusted impressions about it and related the social sciences and humanities to the study of the relationships between human behaviour and their surroundings, or society in general.

Apart from the above, the perception that participants in the interviews had on what should be included was is highly influenced by the perception that the participants have of what the social sciences and humanities are. For instance, some interviewees mentioned that integrating social issues means teaching empathy to students (as the quotation above showed), whereas others mentioned aspects such as territorial planning, or ethics.

Data from the survey also allowed to understand better how professors perceive different social fields, and how these fields related to civil engineering disciplines. In particular, for each social sciences and humanities field, respondents were asked to check those three civil engineering fields that they thought were most related to the specific social dimension. The results to this set of questions are shown in the heatmap in Figure 5.2. The figure shows, in darker colours, those intersecting areas that were said to be more related by more professors, whereas lighter colours represent those areas with less responses by the respondents. The figure also shows a dendrogram, which is often used to visualise hierarchical clustering calculations in tree-structured graphs.

If looked across civil engineering fields, it can be seen that Environmental, Water, and Energy technology are not often perceived as being related to Social communications and relations, Psychology, Culture and history, and Arts and aesthetics. On the contrary, Transport engineering, Buildings and Urban planning are more considered to be related to the mentioned social dimensions. The results also show that Environmental engineering is often seen to be connected to Legislation, Politics, Ethics and philosophy, and Health and quality of life.

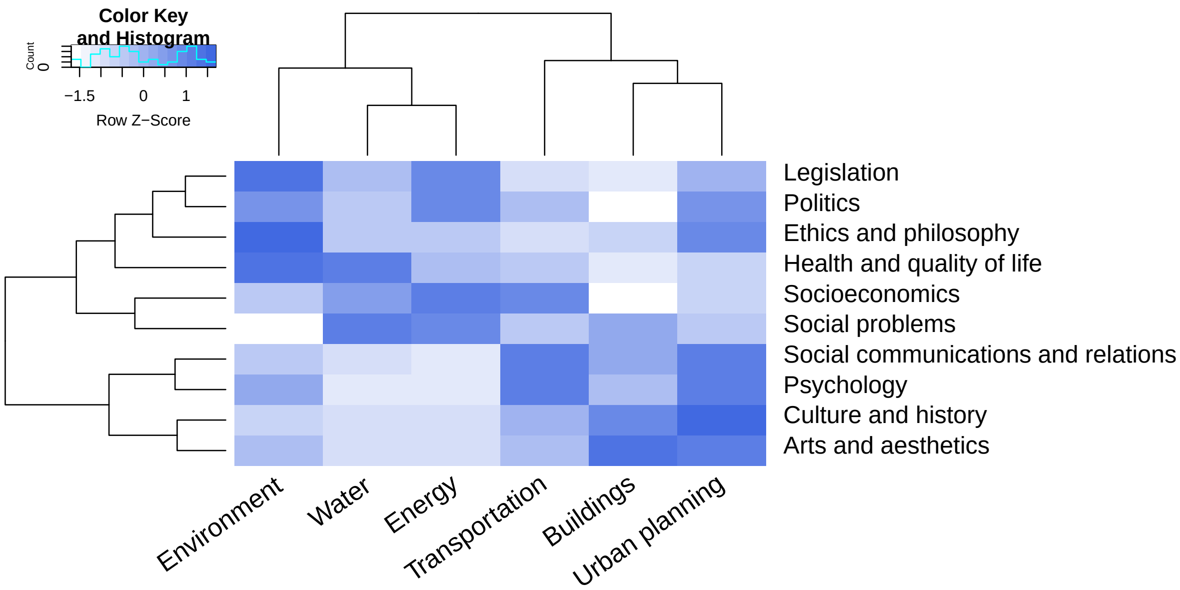

Figure 5.2. Heatmap with the responses given to the perceived relationships between civil engineering and social sciences and humanities fields

While the above analyses corresponded to the perceptions that participants had towards the social sciences and humanities and their relationships with civil engineering, it is also necessary to see what social sciences and humanities fields they considered to be relevant for the civil engineering education. When specifically asked about what to include, there were three broad groups that interviewees mentioned. First, participants often spoke about law and economics as particularly relevant for the profession. Second, ethics was also seen as an area that should be taught for students given the social responsibility of civil engineering professionals. And third, knowledge about the territory was also regarded as fundamental; from the viewpoint of the interviewees, this would include understanding how public works fit within the geography of a region, and what the impacts are on the communities around them. As it can be seen, this is a broad area and it may include disciplines such as geography, sociology, or demographics. Besides from these three groups, other participants mentioned other topics, such as art, which was strongly linked to buildings and bridges.

Data collected from the surveys regarding the question of what should be taught to civil engineering students is shown in Figure 5.3. In this question, participants could choose as many options as they wanted. Socioeconomics, Culture and history, and Health and quality of life were the three social dimensions that were more often chosen, specifically by more than 40% of the respondents. In fact, these results are related to the answers provided in the interviews, as Culture and history and Health and quality of life should be considered as essential when thinking about the territorial dimensions of infrastructure. The two areas that stand out as the least chosen ones are Psychology and Politics, both answered by less than 15% of the survey respondents.

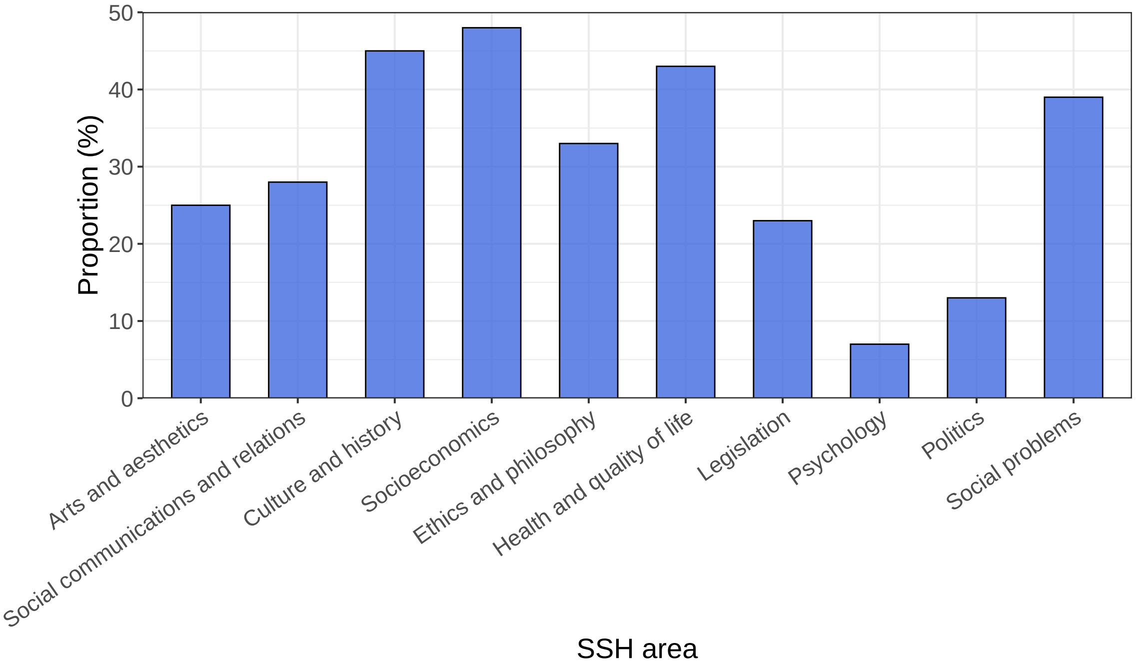

Figure 5.3. Responses given by professors to what social sciences and humanities areas should be included in civil engineering programmes

5.3.2. Training

Training was not regarded as an impediment by all professors, but some participants did say that not having been trained in any social sciences and humanities field made them doubt of whether they'd be able to teach this kind of topics. There were also professors that said that, even though they had not undergone formal training, they did include social issues in their subjects out of their interest and what they read in the literature and the news.

There was a third smaller group of interviewees that did not consider themselves to be well enough prepared to teach these topics, but that introduced them in their courses because their course coordinator motivated and supported them to do it. Again, this shows the importance of personal relationships within groups and departments, which not only may make the environment more propitious but also give more tools to produce the desired changes.

5.3.3. Integrating mechanisms

The availability of specific and commonly agreed mechanisms to include social topics would influence the preparedness to integrate social aspects in civil engineering programmes, both at an individual (professor) and collective (department/research groups) levels.

The perceptions from participants on the mechanisms that should be adopted to include social topics differed regarding different aspects. The main factors characterising mechanisms that were raised by the participants were the specific methods in which these topics may be introduced (the “how”), the year within the education program in which they could be integrated (the "when"), and the profile of the professor to be teaching these contents (the "who").

The "how"

When asked about how social sciences and humanities content should be introduced in their subjects or in the civil engineering programme, there were two main factors that came up: (1) whether social issues should be introduced through single subjects of specific social sciences and humanities disciplines (such as sociology), or through transversal topics in already existing subjects; (2) and whether it should be obligatory or optative.

First, regarding the way in which the subjects should be introduced, opinions by interviewees were divided. On the one hand, some participants shared the vision that it was appropriate to include the social transversally in all subjects, similarly as it would be done with economic or environmental issues.

> "I think maybe these are things [social issues] that should be integrated more in the subjects that already exist, instead of seeing them as something apart. And, in fact, I think it's more effective this way. At the time there was a Sociology subject, a Maria, and I felt like it had nothing to do at all with the rest of the degree. It was something they had put there, and it was more or less interesting but it had nothing to do with the degree. No, I think that these aspects should be integrated with the rest of the knowledge that there is in the degree and not put them aside. I think it also gives the feeling that it is something aside. For instance, art is something more transversal. Or when we see a transportation subject for example. Well, obviously there has to be a social side and on the social impact that it has. And there are many subjects where we need to see the social and environmental impact, not only the economic one."

On the other hand, even though a transversal integration could be adequate, some interviewees argued that including an initial and robust base on social issues was often necessary because students did not have enough previous knowledge on this area. Some of the inconveniences that were mentioned when talking about including specific social sciences and humanities subjects was the fact that this may make them seem as something different or far from the profession of civil engineering, which goes against the argument for including these issues in civil engineering programmes.

Secondly, the issue of whether a subject is obligatory or optative was considered to be very important by some of the interviewees, because it can be perceived by students as if the former were essential, and the latter were not as important for the professional practice. Nonetheless, it needs to be noted that in the institutions that were included in the study, most of all the specifically social subjects (such as ethics, social impact of infrastructure) were optative, and some had been obligatory in the past but had changed to optative in the last years. One of the professors described his experience with one of these subjects, called "Civil engineering for society":

> "Our subject is optional, and it has a high enrolment. This shows that it is either a María, how it is commonly said, that it is easily passed –which is also a selection criterion for students, no? – or that really students in their last year want this type of subjects. It has no exam, but we make them reflect a lot, they need to give in three reflection essays during the course. And they are not used to these things."

Regarding the reasons why students choose these subjects, more information should be gathered, including the perspectives from students themselves. However, a few interviewees mentioned that students were truly interested in these subjects, and this was shown through quantitative indicators (mostly student satisfaction surveys and the number of students enrolled every year) as well as other factors. For instance, one participant declared that "students attended a lot to class", and asked him to supervise their undergraduate or graduate theses.

A difficulty that was mentioned by some interviewees regarding the inclusion of optional social sciences and humanities subjects was the limit in terms of resources. A participant talked about the trade-off between adding more optative subjects and the number of students that would enrol:

> “So, there are things that should be there [in the curriculum]. What is the problem? That the credits of each degree are what they are, and we try to give the best technological training, the most relevant, the most complete. And then there is this part of optionality, and what happens with it is that there are very little subjects. And I think that they do not dare... I do not speak about the university, but in general. In other centres do not dare to offer a very wide catalogue of subjects because they think that a subject that will be taken by two or three people is not viable. But of course, with that mentality, you will never offer it. You don’t know how many people would take it. So, there are things that, I think, would have to change.”

Most of the above questions were also reflected in the data collected from the surveys. Figure 5.4 shows the answers to the question of whether social sciences and humanities should be included in the education of civil engineers. If respondents chose “yes”, then they could choose between four different methods through which SSH should be included in civil engineering studies. The options were: adding specific social sciences and humanities subjects in civil engineering studies; adding social sciences and humanities contents transversally in already existing subjects; attending conferences and seminars (not necessarily at university) related to the social sciences and humanities; and finally, learning about social aspects through professional experience.

It can be observed that the methodology that most respondents considered adequate to incorporate social aspects in civil engineering education is through addition of social content in existing subjects, which was chosen by around 50% of the respondents. Besides, the number of responses collected for the options “adding social sciences and humanities subjects” and “through optional seminars” was very similar, corresponding in both cases to around 20%. Lastly, less than 5% of respondents believed that civil engineers should not be trained in social areas but should acquire the corresponding knowledge through professional experience.

There was one respondent that chose the answer “Others”, in which case possible alternatives needed to be offered. In this case, the respondent said “The first two answers”, which namely meant adding social sciences and humanities subjects and adding social sciences and humanities contents at the same time.

Potential differences between groups of respondents of the survey were analysed using diagrams, and the chi-square tests. Figures 5.5 and 5.6 show the responses presented in Figure 5.4 divided by sex and by years working as a professor respectively. The choice of these two groups of respondents has been done for two reasons. First, regarding sex, because the gender perspective is a relevant issue in the context of engineering degrees given the differences that there have been over the decades. Second, regarding the years at university, in order to see whether perceptions change across time and experience.

Firstly, regarding gender, results of the chi-square tests showed that there is a significant relationship between gender and the responses to this question, $\chi^2(4, N = 81) = 11.1, p = 0.025$. From the graph in Figure 5.5 it can be seen that there are major differences in two of the responses. On the one hand, a higher proportion of male respondents answered that social sciences and humanities contents needed to be added to already existing subjects. On the other hand, more female participants included their own response through the “others” option.

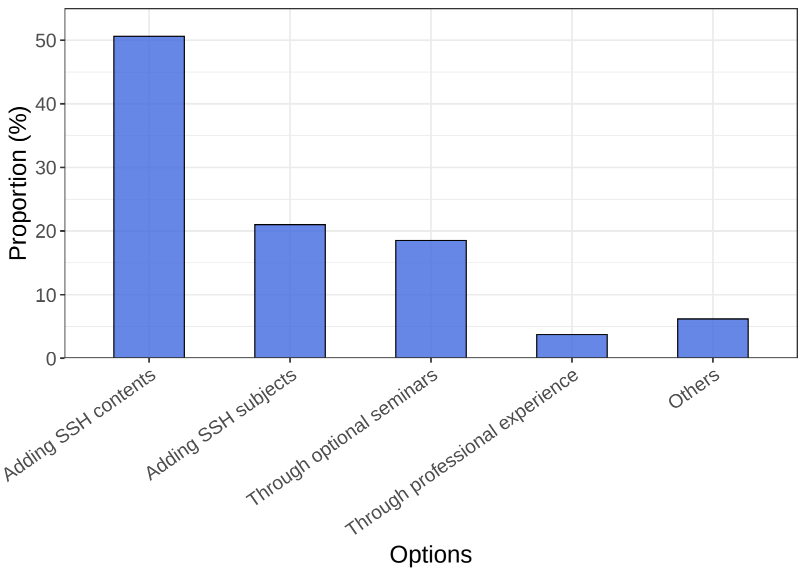

Figure 5.4. Answers by professors to the way in which social issues should be included in civil engineering programmes

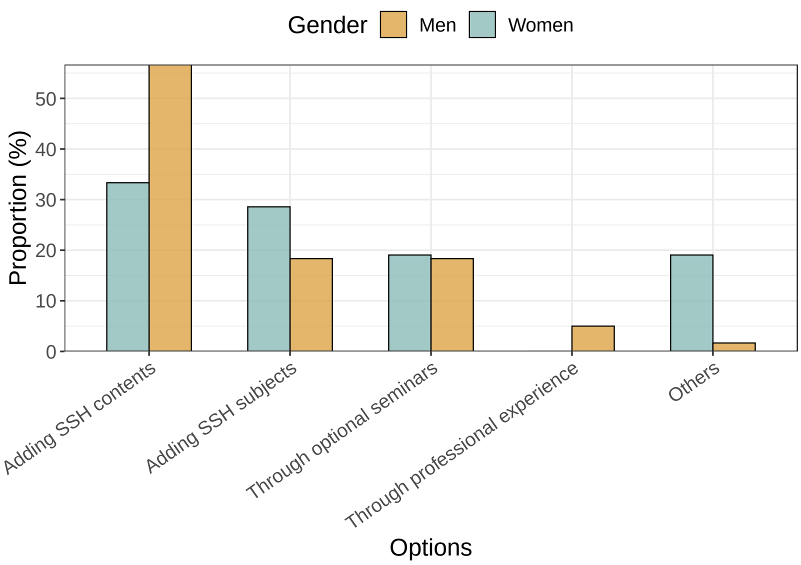

Figure 5.5. Answers by professors to the way in which social issues should be included in civil engineering programmes, separated by gender

Secondly, results of the chi-square tests between years working as a professor and the responses to this question did not show a significant association, $\chi^2(16, N = 81) = 22.5, p = 0.129$. Besides, from the bar chart in Figure 5.6, there does not seem to be a particular trend over the years. It could be said that a higher proportion of respondents with more experience answered that social sciences and humanities should be introduced by integrating specific contents in subjects, whereas professors with less years of experience considered that social sciences and humanities subjects should be added.

The "when"

There was no common agreement on the issue of the moment in which civil engineering students should be introduced to social aspects. As it was argued by some of the participants, introducing social

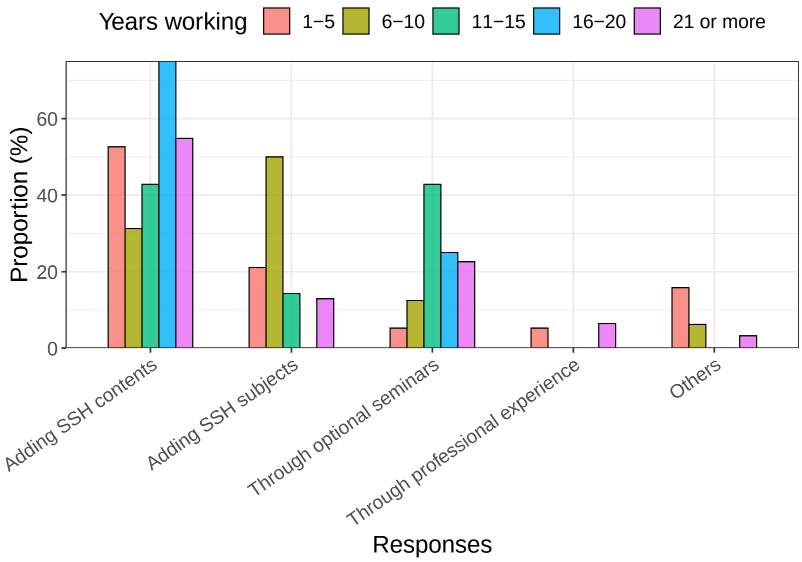

Figure 5.6. Answers by professors to the way in which social issues should be included in civil engineering programmes, separated by years working

content related to civil engineering in the first years could be too early, as students were not mature enough to critically discuss these topics, and also they did not know as much about the profession so as to relate well the two dimensions. Nonetheless, only introducing these aspects in the last year was deemed inappropriate by some participants, who explained that when they arrived to the fourth year, they were already shaped and it was too late. Besides, according to some professors, in the last year students tend to be focused on finishing, and also do internships, which makes them try to take those subjects that can be more easily passed.

One participant showed their personal experience of having studied a civil engineering program that had a few social sciences and humanities subjects. According to this participant, the integration of topic topics in the civil engineering program should be done progressively so that students could gradually understand their value and contextualisation within the program. In her own words:

> “It’s difficult. It’s difficult because... I tell you, from my own experience I think I was so immature when I started the degree that if they had come to talk to me about social issues... I wouldn’t be very capable of giving them the value that they have. I think that maybe it would have to be incorporated little by little, right?”

One of the interviewees, who is a sociologist, mentioned the following:

> “I believe that, in general terms, in the first two years, which are more general, there must already be a framework with a certain sociological orientation, because sometimes they are not aware that they are also subject to criminal law. And this is very important, huh? And then already in the following courses, there can be something in more specific fields, like social impact assessments. That is already a little bit, when the student is already more trained in what is engineering. Just a little, because the student does not have to know everything or learn everything, but to be open enough so that he is able to open up, and then learn other things added, and about that interdisciplinary conception. They keep on building that way of looking at things, and in the future, they will learn more, but the base needs to be clear.”

It needs to be noted that most participants linked this aspect with the maturity level of students. Additionally, apart from maturity, some interviewees also talked about the type of subjects that there are in the first years, which tend to be less applied sciences:

> "Do you know what happens? That in the first year there is Physics, Mathematics, Chemistry, Drawing and Economics. Maybe the Economics subject is the one in which they can discuss more things. The rest of the subjects gives little space to make reflections. So, well, it's fine as a start, but I understand that things of that kind are perhaps more practical in later years, in second, third, and mostly fourth years, because on the final project there may be questions like that."

Finally, regarding this last issue, it needs to be mentioned that there was a group of professors in the subject of Chemistry that had managed to prepare an activity in which a moral dilemma related to construction materials was posed to students and they had to critically think about it, and carry out a debate in class. This proves that, even though this kind of subject is frequently seen as having little connection with social issues, relationships can be found between the study areas of these subjects and society.

The "who"

When discussing the profile of the person that would be suitable to teach social subjects in a civil engineering program, the results showed that there was not a unified idea of what background such educator should have. The proponents of specifically requiring a professor from a social sciences background were scarce, and they argued that such requirement was necessary for students to relate to people other than civil engineers.

> "We live in a globalised world, so it seems basic to me that we need to get used to collaborating. We are all competent in a specific part of a project, so if a student that finishes at the civil engineering school has only had contact with civil engineers... It sounds like a bad start to me. They [students] should deal with economists, architects, sociologists... It is fundamental."

Hence, this perceived requirement did not appear to be related to the ability or not of the professor for teaching in this area, but for the added value for the students in terms of the professor's interdisciplinary vision. In general, there was an agreement on the fact that such educator would have to possess knowledge (either formally of informally obtained) both on the social sciences and humanities and civil engineering, and to be able to adapt the social knowledge to the civil engineering domains. As an interviewee mentioned, "it could be a sociologist, but also with knowledge of civil engineering, and know how the sociological topic applies to the field of civil engineering. It would be related to the practical application of the civil engineer's task to society."

In fact, in one of the institutions there was a Sociology course in the 1980s, but according to the participant that mentioned it, it "felt like it did had nothing to do at all with the rest of the degree."

5.4. Willingness to embrace social aspects

Even when professors did not identify particular barriers in their ability to make changes in the programmes, or in particular to integrate social content, this did not directly mean that they were eager to make such changes. Hence, this section analyses the willingness of participants related to the issue in question through four main points: the overall willingness, the potential influence of incentives for such willingness, the "Yes, but not in my subject" phenomenon, and the effect that individual interests have on the willingness.

5.4.1. Overall willingness

Among the 23 interviewees, only one said that social topics should not be included in the curriculum of civil engineering degrees. When giving this response, the participant recognised that his opinion was not a popular one and said that “I do not know if this is the answer you expected or if it is uncomfortable, but it is what I think”. It needs to be noted that this professor had a particular interest for some areas of the social sciences and humanities, such as art, history, and culture. Nonetheless, from his perspective, the social dimension and civil engineering should be dissociated. In Spain, civil engineering has had over the years a prestige for being a highly technical and complex discipline, and changing the education would be degrading for the profession. When discussing the current challenges in civil engineering education, he mentioned the following:

> “I believe that the first challenge is not to lose the north. Not to distort the reason for which the civil engineering schools were created. The fact of trying to humanise or incorporate more social sciences... I believe that all this responds to the intention of giving a profile to training that is more adapted to society. But simply because the initial role [of the civil engineer] is becoming blurred it is because what the civil engineer had to contribute to society has practically already been contributed, we already have a well-established welfare society and technicians who were key in the development of society a hundred years ago... well, now that development has already been achieved and what do we do with them? We don’t need so many civil engineers. So, I think that what needs to be re-evaluated is how many schools, how many civil engineers we want to train, and that they are competent civil engineers in their work as civil engineers.”

As it can be seen, this interviewee was contrary to the idea of changing the civil engineering education and proposed instead decrease the number of trained civil engineers to avoid what he felt would be training engineers with a low profile of physics and maths, and a higher profile in social sciences, which would mean not having competent technicians when there were major civil engineering problems. The idea of decreasing the total number of civil engineering schools in the country was not raised by any other interviewee, but it was mentioned by some professionals in the focus group with practitioners.

Regarding the aspect of engineers not being competent enough for civil engineering tasks, other participants in the interview explicitly mentioned that they did not believe that both elements, the social and the civil engineering, would be substitute of each other. In fact, according to several participants, it would help “humanise” civil engineers.

Having said this, the high proportion of interviewees agreeing on the need for integrating these issues was also reflected in the responses given by professors to the survey. Among the responses, less than 1.5% said that these aspects should not be included.

It needs to be noted the fact that most interviewees agreed to the importance of including social sciences and humanities in civil engineering education, could arise the question of whether there was a bias in the sample. As it has been said, this high percentage of acceptance by interviewees was also reflected in the responses given to the surveys, and reliability and validity of results measured was high. Professors who were sent the survey and accepted to answer it could have been attracted by their interest for the topic. Nonetheless, this apparent bias could also be explained either by the fact that giving such answer is politically correct, or by what will be explained in Section 5.4.2, related to the issue of agreeing to the need for these topics but no wanting to introduce them themselves in their subjects.

As it was mentioned above, the university system is perceived as an environment in which getting promoted is difficult. Most participants did not feel that there would be individual or personal benefits for integrating SSH (or any other new content) in their subjects, as teaching duties were not systematically considered when professors undergo external evaluations.

On the contrary, as it was highlighted previously, the way to establish themselves in the schools was to publish and obtain funding for research projects. Related to this, some participants were sceptical of the fact that they would be able to obtain any tangible benefit from it. One of them reasoned the following:

> “The problem of university is that it is almost impossible to give an economic incentive, which in the end is what attracts more people. Sometimes they give incentives that are like... exchange cards . I give you,... I don’t know, I free you from 10 hours of class next year, or I give you money that you can use for buying things for university. So, we are not being paid because they can’t”

In fact, incentive systems and promotion processes in HE have been studied in the literature before, and the perceptions collected during the interviews are, to a greater or lesser extent, in line with what authors have concluded in studies based in other countries. Gourley and Madonia (2021) investigated the effects of tenure on instructor quality as perceived by students. They describe how some systems require that professors excel at research, and incentives for professors to dedicate more time to teaching tasks are not clear. They found that after being granted tenure, teaching quality of professors slightly decreases. El Ouardighi et al. (2013) compared the professors’ allocation of efforts on research and teaching and modelled the equilibrium between the two tasks using a two-state equation capital accumulation model. Regarding the emphasis given to research, which arose frequently in the interviews, Bak and Kim (2015) carried out a study to examine how changes in incentive systems changed evaluations given by students.

Some professors that showed more willingness towards the introduction of SSH in their subjects particularly mentioned their personal interests towards the intersection between social sciences and humanities and civil engineering, and saw it as a personal growth benefit, together with the opportunity of training future engineers in this manner. Besides, a few interviewees highlighted the fact that they had consciously made the choice of opening towards this area, even when this meant a potential disadvantage in terms of other factors, such as publications.

Concerning the direct impact on research, interviewees that had done research in interdisciplinary areas highlighted that publishing usually tended to be more costly in terms of time, because of the need for dialoguing with researchers from other disciplines or, in general, the social science methodology which is perceived as more time-demanding than some civil engineering research areas such as modelling, which does not necessarily require external collaborations.

5.4.2. Yes, but not in my subject

In planning and engineering, there is a concept that is referred to as “Not in my backyard” (NIMBY) referring to the reaction of citizens when infrastructure projects that are considered potentially dangerous are built around their homes. A similar concept arose from the data collected. Even though many participants acknowledged the need for integrating social issues in the subjects, some of them reasoned that there was no space in their subjects to include them, or that such integration should be done somewhere else in the curriculum. Something that could be referred to as “Yes, but not in my subject” (YBNiMS).

In fact, the attitude and commitment of professors was raised by one of the participants, who mentioned that apart from including social issues such as ethics or globalisation, it is important that professors act accordingly. Namely, that they act fairly, or that they empathise with students. Another participant also emphasised that not all professors are committed in the same ways.

The above situation was also analysed using data obtained from the surveys. Figure 5.7 shows the bar plot for the responses given by the professors without disaggregating by group. Results are shown in percentage, proportionally to the total number of professors responding the survey.

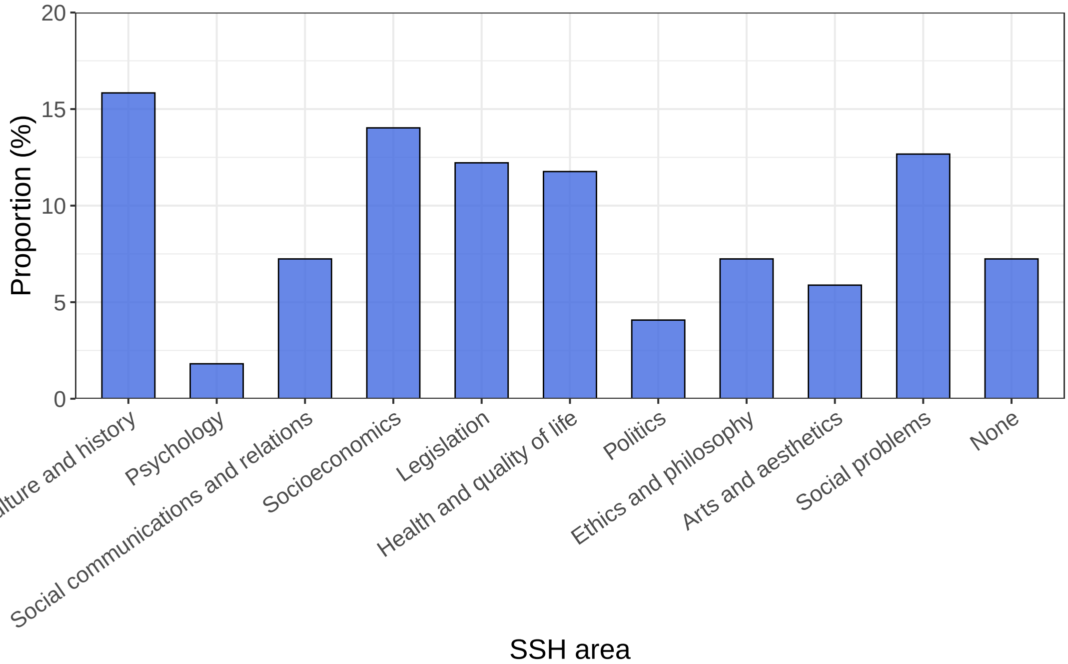

Figure 5.7. Perceptions by professors of what they actually teach in class

As it can be seen, a higher proportion (above 15%) of professors consider that they introduce elements related to culture and to social problems in their subjects. Between 12 and 15% of the professors answered that they introduce aspects related to Socioeconomics, Legislation, Health and quality of life and Ethics and philosophy. Less than 7.5% of the respondents considered that they include aspect related to Arts and aesthetics, Politics, and Psychology. Around a 7.5% of the respondents acknowledged that they do not integrate any of these social topics in their teaching activities.

These results need to be contrasted with those represented in 5.3. When participants were asked what social issues should be included, Culture and history, Socioeconomics, Health and quality of life, and Social problems were also the ones that were chosen by more respondents. At the same time, Psychology and Politics were the ones that were considered to be less necessary in civil engineering programmes. However, while for instance Culture and history, Socioeconomics, Health and quality of life, and Social problems were chosen by more than 40% of the participants when asked what should be included, they were only chosen by around 15% of participants when they were asked what they actually include in class. Again, these results may point at the fact that, while SSH are said to be important, in reality such importance is not reflected.

In order to examine the results from a gender perspective, Figure 5.7 shows the same results of Figure 5.7 but disaggregated by sex. The graph shows that there are three knowledge areas that present larger differences in the responses given by male and female respondents, even though the chi-square tests did not show significant differences between any of the knowledge areas and the declared sex.

The three knowledge areas that show larger differences in the graphs are Culture and history, Ethics and philosophy, and Social problems. In the case of culture and history, the proportion of male respondents that declared that they include these issues in class is of around 17%, while the proportion is of a 10% for female respondents. For the case of ethics and social problems, it was the female respondents that stated more in a higher proportion that they include this kind of aspects in class.

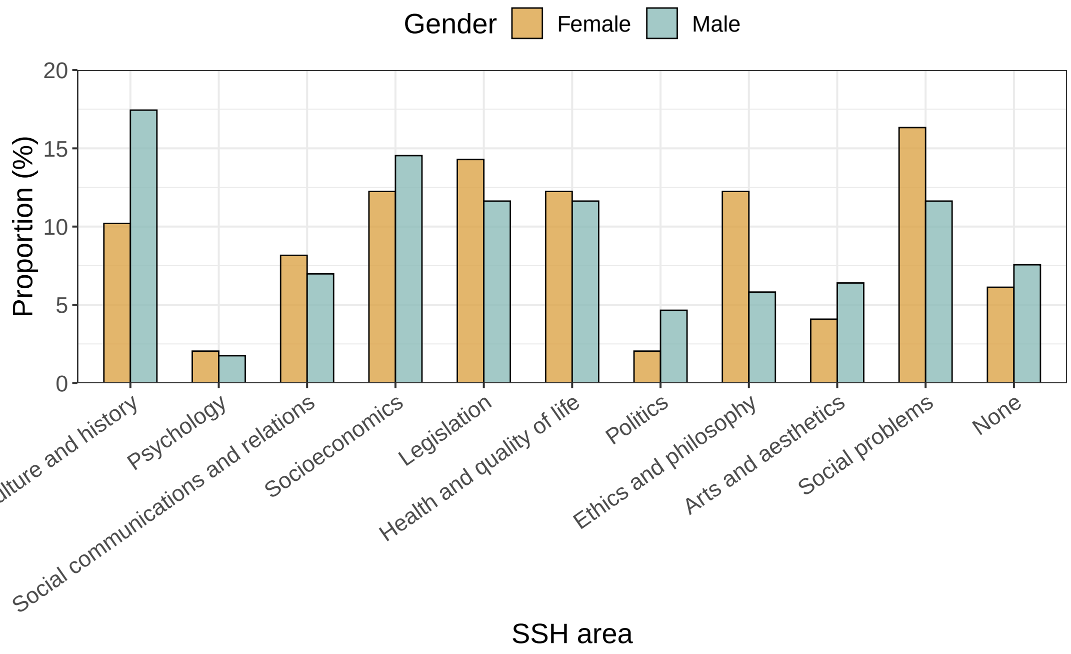

Figure 5.8. Perceptions by professors of what they actually teach in class, by gender

5.4.3. Career paths and personal interests

Different participants showed different motivations for having chosen to teach and do research in a civil engineering school. This was related to different levels of motivation for social aspects. It needs to be noted that there seemed to be a perception among some participants that professors from areas such as materials or structural analysis would not be as interested in these topics as professors from urban planning or environmental engineering. Nonetheless, there were actually professors from chemistry, for instance, that were very committed to doing cooperation projects, or a professor from the field of pavements that was also very motivated by these issues.

Data from the survey was used in order to examine whether this perception was also reflected in the questionnaire responses. Chi-square tests only showed significant associations between the field of speciality and the SSH area to be included for the case of the test between the inclusion of legislative contents and the field of the professor, $\chi^2(8, N = 82) = 16.65, p = 0.03$.

In Figure 5.9, the responses to what should be included in civil engineering education is shown. On the x-axis, the various social sciences and humanities areas are presented, whereas the y-axis represents the speciality field of the respondents.

5.5. Propitiousness for change

5.5.1. Sustainability as the driver

Some participants mentioned that issues related to sustainability make it necessary to modify civil engineering education, and as part of this modification, integrate more social aspects. In fact, one of the institutions analysed was going through a thorough process in which all the professors had to choose at least one SDG and integrate its vision in their subject. This topic was raised by absolutely all the respondents from this institution and some interviewees mentioned that there was quite a lot of participation and interest. The director of this school described this process as follows:

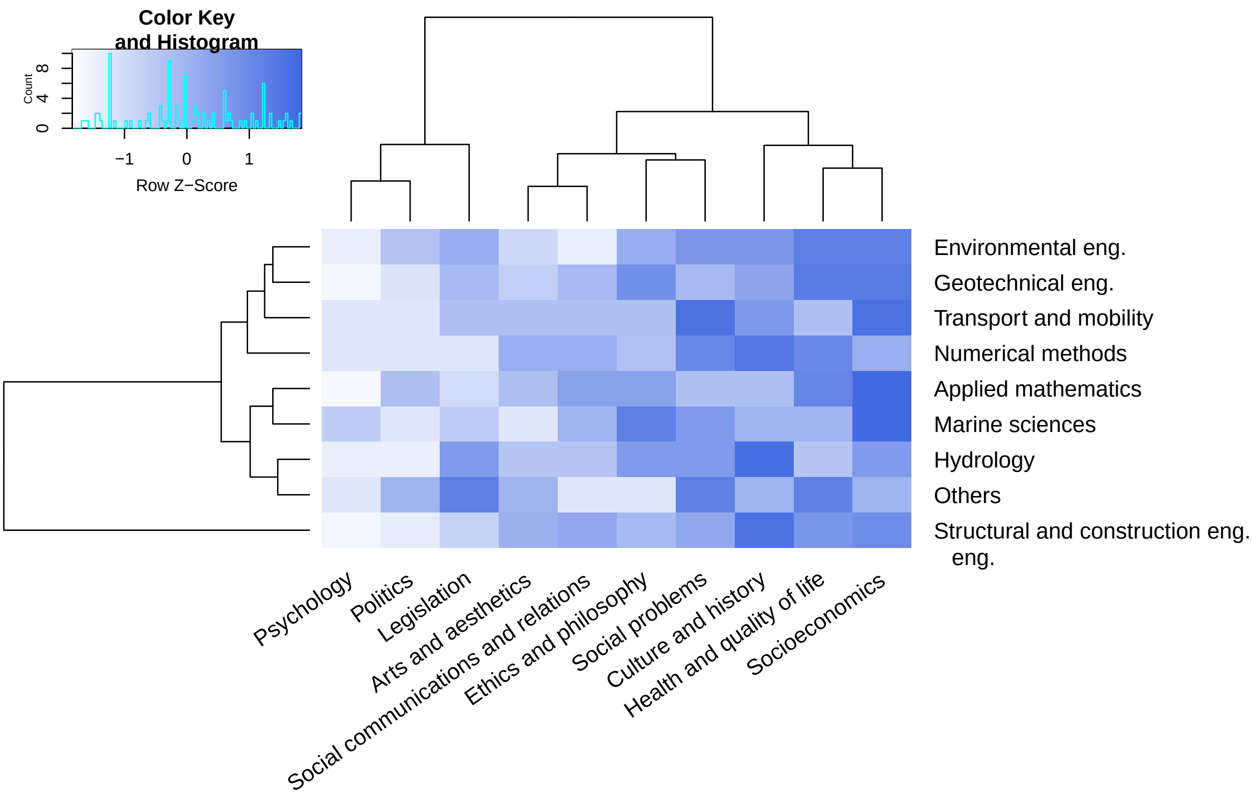

Figure 5.9. Heatmap showing research specialisation of professors and what they perceive should be included in civil engineering education

> “We, for example, what we are doing now in the very short term, is inserting the Sustainable Development Goals transversally into the degree. How do we succeed in that? Well, little by little. We speak to every professor, and we ask him ’without changing your plan, what are the Sustainable Development Objectives that align best with your course?’ Some subjects, for instance water, align perfectly. For mathematical subjects it is no longer so clear. So, we have been doing this task for about a year, but let’s see, trying to put all that [sustainability] into the philosophy of the school. Notice that this does not imply much, it just involves talking to the professors, convince him to align with the SDGs, etcetera, etcetera. And that is sometimes complicated.”

Regarding the greatest difficulties that they were finding, he mentioned the need for finding ways to include the objectives in highly technical or scientific subjects, such as construction materials.

A participant, who is a sociologist, from an institution different from the one above also mentioned that the space where they had found that social sciences had more room was in sustainability subjects.

5.5.2. Status of the profession of civil engineering

Most participants mentioned, in greater or lesser detail, the historical evolution of the civil engineering profession in Spain, which they related to the need for changing the civil engineering education and thus integrating (or not) knowledge from SSH areas. Every participant gave more or less emphasis to the following three elements: the degradation of the profession, the impact of the 2008 crisis, and the change in national needs in terms of infrastructure.

In Spain, the perception of society towards the profession of civil engineering has suffered a process of “degradation”, in which society no longer trusts the construction industry. According to some participants, corruption and a lack of transparency in the industry has had a big effect on this decay. A well-known corruption case related to the construction industry is the “3% case”[5].

Another aspect raised by respondents was the consequences that the 2008 crisis has had on the construction sector. This has also contributed to a change in societal perception of the profession. In fact, in Spain, civil engineers used to be considered as “almost gods”, as stated by two participants. They represented an elite that has visibly been affected by such crisis and by the news about corruption.

Finally, another aspect mentioned by the participants is the fact that the needs for civil engineering projects have changed. While two decades ago new infrastructure was still necessary, and more predominant, the needs right now are in terms of maintenance and service operation. This change of paradigm introduces new (or less looked at in the past) fields for the profession.

5.5.3. Status of the civil engineering education

According to some of the participants, as a consequence of the status of the profession above-described, the number of students registering into civil engineering programs has decreased enormously in the last years. In fact, this is supported by data existing on the number of students registering in the various schools, such as in the data repository of the Universitat Politècnica de Catalunya[6].

As it was outlined above, in the past, civil engineers were considered as being part of an elite in Spain. Therefore, having that degree implied having a good position after. However, this paradigm of elitism changed. As one participant put it:

> “The civil engineers that finished the degree in the past, after six years of studying, had a training that was useful for anything. There are some of my classmates that are now working in very, very diverse fields. Many are civil engineers, but others are working in consulting companies for instance. Others... I have a classmate for instance that has done the Paris-Dakar or another one that won the American Sailing Cup. Namely, since the civil engineering education was so selective, the result was a very versatile professional, an all-terrain, an all-proof.”

The director of one of the institutions in which interviews were carried out, as well as some professors, mentioned the need for making the degree more attractive through marketing. This would involve changing the name of some subjects, but also adding new content that would attract more students. It needs to be noted that this was seen as negative by a few participants, who mentioned that doing that would go in detriment to a “respected profession”, and that it was necessary to “respect our past as engineers”.

Even though the majority of the participants shared the vision of a need for changing the education to attract more students, one interviewee mentioned that what is needed is to decrease the number of civil engineering schools in Spain. As this participant argued,

> “there are too many civil engineering schools. Too many. If society demands specialists that have training on... economics, sociology... then those are new degrees that need to be created. I think that it is a question of respect. We need to respect our past. And if there are only four left that want to study civil engineering, then they go to the school that gives such training. If society really needs that there are always new degrees, it is because society is dynamic and

[5] See El Economista (2019). *La construcción, un sector manchado por múltiples casos de corrupción*. https://www.eleconomista.es/empresas-finanzas/noticias/9807503/04/19/La-construccion-un-sector-manchado-por-multiples-casos-de-corrupcion.html [Accessed 2021/3/31] (in Spanish)

[6] Available at http://dades.upc.edu [Accessed 2021/6/28]

> there are new needs. Such as with the topic of communications. In the last 25 years, there have appeared new professionals, new degrees. All this has been required by society. So, if society needs a new training, then they need a new degree. It would be better to start from zero than to try to fix something... It is like wanting to transform a tricycle into a bike. Well, maybe it is preferable to leave the tricycle and design a bike from scratch.”

5.5.4. Personal relationships

Several interviewees made direct references to relationships between professors. In particular, some participants expressed that they had found themselves more comfortable about suggesting changes in the programme (including the integration of social issues) in environments where relationships with the other faculty members were smooth or in “relaxed environments”. At the same time, some of them described the impact that the compartmentalisation into several departments of the civil engineering school had had on these same relationships.

Besides the above, the leadership of or admiration to some professors was also shown to be a driver of more propitious environments for changes at different levels. For instance, a professor in the area materials mentioned the following:

> “If you had asked me some years ago about my interest in social issues, I would have said that I don’t see the point of understanding them. I had not realised their importance. Now it’s the opposite. Now I interact with a professor in the school... she is an excellent historian, a person who transmits a lot of information in a very entertaining, very interesting way. She links it to roads, to concrete... I think that my interest in social issues has awakened. I think that a little by dint of traveling, of meeting other groups, of working in broader, more transversal projects... that has indeed changed my mind.”

As for the spaces for debate that there are for this kind of discussions, the majority of participants acknowledged that they are usually informal spaces (such as cafeterias, corridors, outdoor surroundings of the school...) rather than formal spaces such as seminars that are specifically created with this purpose.

In addition to relationships between professors, a minority of participants mentioned as well relationships between professors and students. They declared their perceived importance of building a good rapport with students so that they feel more comfortable expressing their opinions in debates, which are more common when teaching social issues, as well as for leading by example to teach some transversal skills like empathy or communication.

5.6. Summary

In this chapter, the factors affecting the process of integrating relevant social content in civil engineering programmes was analysed from the perspective of professors and based on the mixed-methods approach described in Chapter 2.

These factors were grouped into four elements as it had been done in Chapter 4, namely ability, preparedness, willingness and propitiousness. These elements help to explain what hinders the integration of relevant content from the social sciences and humanities in civil engineering educational programmes. For the understanding of these four factors, the combination of quantitative and qualitative data was favourable to understand some aspects more in-depth.

Regarding the above, a first observation to be made is that data from the interviews reflect the importance that factors that are not directly related to social contents in civil engineering education have, such as the legislative structures that govern university systems, the system of “incentives” given to professors for carrying out specific tasks such as teaching innovation activities, or the personal relationships existing between professors, and between professors and students.

A second observation is related to the particularities of Spain that affect civil engineering education, which differ from other countries that were analysed in the previous chapter. More specifically, three principal factors may be considered among these particularities.

The first difference with the conditions in other regions is the situation of the civil engineering profession. Such situation was highly influenced by the 2008 crisis and some cases of corruption within the construction sector, where the profession gained a highly negative reputation among citizens. Additionally, another parameter related to the situation of this field is the way in which it was originally conceived and the elitist role that civil engineers had in society during the 20th century.

Related to the above, it needs to be said that, in the situation of the profession of civil engineering in the country, the civil engineering professional associations play a major role to shape the debates in the industry and, consequently, among professors in academia.

The second element to consider is the university system and the ways in which faculty members establish themselves in the schools. This includes the selection procedures, and the types of positions, including both tenured and non-tenured positions. Regarding the selection procedures, both in the international and Spanish cases, the importance given to number of publications was emphasised as one barrier for professors to integrate social aspects in their subjects due to the amount of time publications require. Nonetheless, a differential aspect detected between the two cases is the professorship system in Spanish universities. This factor was found to be an obstacle for finding a stable position in academia. An example of this is the position of the associate professor. Theoretically, this corresponds to those professors regularly developing their activity outside the University and that are hired on a temporary and part-time basis to contribute their knowledge and professional experience to the University. Nevertheless, in practice, there are associate professors that obtain their main earnings for such position.

The third element to account for is the structure of the educational system, including pre-university studies, and HE ones. Regarding pre-university studies, some participants emphasised the fact that, currently, high school students wanting to study civil engineering need to take a scientific path early and drop social sciences and humanities subjects a few years before entering university. As for undergraduate studies, the civil engineering programmes in the schools analysed were such that eligible courses were allocated in the last years of the degrees. This had decreased the probabilities of finding social contents in the first years of the undergraduate studies. Additionally, while in other countries it is frequent to find the option in civil engineering degrees to take subjects from other social sciences and humanities faculties, this is not common practice in Spain. One of the reasons for this is the fact that civil engineering degrees are mostly found in technical universities and, therefore, there are no degrees at the same universities that offer social sciences and humanities subjects.

Finally, an important debate in engineering education revolves around the issue of seeking a balance between a deep disciplinary knowledge in civil engineering or less deep but broader knowledge. There exists no consensus yet on this question, even though in the last years the tendency in engineering education has been towards depth rather than breadth.

While fostering a deeper exploration into fewer topics is important for the development of engineering professionals, throughout the thesis it has been argued that there exist several reasons for which civil engineers may need to better understand the social side of their profession. Hence, exposure to several social topics can also be considered to be relevant.

The lack of agreement on the emphasis of depth or breadth could be due to the fact that different civil engineering disciplines may require different levels of interdisciplinarity. In fact, several interviewees participating in the study mentioned the fields of geotechnical engineering and structural analysis as examples where the social is not so easily introduced. At the other extreme, disciplines such as urban planning do require a higher level of competencies related to the social sciences and humanities.

In conclusion, while it is not easy to satisfy both ends of the spectrum, it is possible to seek a balance in the contents included in the curricula. In some schools, this may be easy when the last years are dedicated to specialising in a specific civil engineering discipline. Additionally, integrating more content on the social context where civil engineering projects are developed in existing subjects is a measure that could easily be carried out and which would suffice to foster critical thinking around infrastructure development.

6

Comparison of perceptions between students, professors and practitioners

6.1. Introduction

A first important issue arising from the results discussed in Chapters 4 and 5 is the importance of how "the social" is conceptualised by different stakeholders in the context of civil engineering. Chapter 3 proposed a framework for understanding relationships between various areas of the social sciences and humanities and civil engineering. However, due to its predominantly theoretical nature, such framework was not fed by perceptions of individuals involved in educational or professional tasks in civil engineering.

In Chapters 4 and 5, the perceptions by professors were analysed by combining qualitative and quantitative data. Nonetheless, it is particularly relevant to examine with more detail the construction of the social by various groups, and this is why the first section of this chapter analyses it by comparing the responses by students, professors, and practitioners, and those by male and female respondents. Understanding how the social is perceived by different groups is particularly relevant to know whether significant conceptualisation differences exist and whether these affect the willingness that they have to utilise these issues in teaching and the profession.

In addition to the above, a second observation that needs to be made is that up until this point, the analysis of the perceptions towards civil engineering education has focused on professors. Even though interviews were predominantly carried out with faculty members, the survey was also answered by students. Therefore, it is important to analyse the main points discussed in Chapters 4 and 5 with relation to the integration of relevant content from the social sciences and humanities from the perspective of students. It needs to be noted that the perspective of students is important at this point because it was not possible to detect barriers imposed by students using data from the interviews. Besides, understanding their point of view towards these topics may help in the proposal of more adequate guidelines in future curricula.

A third aspect that has not yet been explicitly handled in this thesis is the issue of competencies. In the last decade, the engineering industry has seen an increase in the demand for engineers with broader profiles rather than technologically specialised ones (Amadei, 2019, Scott, 2012, Wikle and Fagin, 2015). This grown interest has been attributed to the need for engineers to solve complex global challenges that need to be tackled through an interdisciplinary lens (Walther et al., 2017), as well as to other factors such as graduate employability (Succi and Canovi, 2020). These challenges are such as climate change, emergency management, or access to basic needs facilities.

This engineer is sometimes referred to as the "global engineer" (GDEE, 2014, Hundley et al., 2013, Mazzurco et al., 2012). Several authors have debated the question of the competencies defining this new conception of the engineer. For instance, Canney and Bielefeldt (2015) highlight the need for engineers to be socially aware and responsible; Allert et al. (2007) and Mazzurco et al. (2012) emphasised the need for intercultural skills; and Amadei (2019) advocates for the need of engineers to understand their role in society, the consequences of their decisions on different socioeconomic, cultural, and political dimensions.

These fundamental competencies can be developed after graduating, albeit fostering them at an earlier stage during undergraduate and graduate studies has been considered to be effective (Clark, 2011, Dodrige, 1999). Despite the acknowledgement of the importance of educating engineers from a broader perspective, there are still no clear directions as to what exactly the qualities that need to be instilled in engineering students are and how engineering educators can support the attainment of such skills by students (Van Maele et al., 2013). What is more, some researchers have found that the perceptions towards these different skills are different among academics and industry (Patacsil and Tablatin, 2017), a fact that may be hindering the effective development of future engineers.

Having said this, in the following sections, the three comparative studies introduced above are presented as follows:

1. First, the concepts of the social contribution and social dimension of civil engineering are analysed. This is done by contrasting perceptions towards the social sciences and humanities by professors and students.
2. Then, perceptions regarding engineering education among different primary stakeholders are examined so that results from previous chapters can be contrasted to a different setting.
3. Finally, the objectives of the last section of this chapter are to contribute to this debate by analysing perceptions towards social competencies that different stakeholders within the civil engineering academia and industry have.

6.2. Social contribution of civil engineering

This section examines the perceptions that different respondent groups (new students, undergraduate students, graduate students, professors and practitioners) have regarding the social dimension of civil engineering. This is done on the basis of four different questions included in the survey, which had the objective of understanding better how the social contribution of civil engineering is perceived and what its relative importance is.

6.2.1. Comparison with other disciplines

A first approximation to understanding how the social contribution of civil engineering is perceived was analysed on the basis of the responses to a question related to the perception that the respondents had towards the importance of the contribution that eleven different scientific and technological fields make on society. Note that the fields were chosen in order to match different classifications that have been made in the literature of the fields, so that the list was not intended to be exhaustive, but to cover various types of disciplines.

6.2.1.1. Descriptive analysis and associations between variables

Figure 6.1 shows the results obtained to this question through box plots. The bottom part of the boxes represents the first quartile, whereas the top part represents the third quartile. The second quartile (the median) is shown through a bold line. Besides, the mean of the data is represented through a diamond. The vertical lines go from the lowest data point to the highest one. Data outliers are represented through black dots.

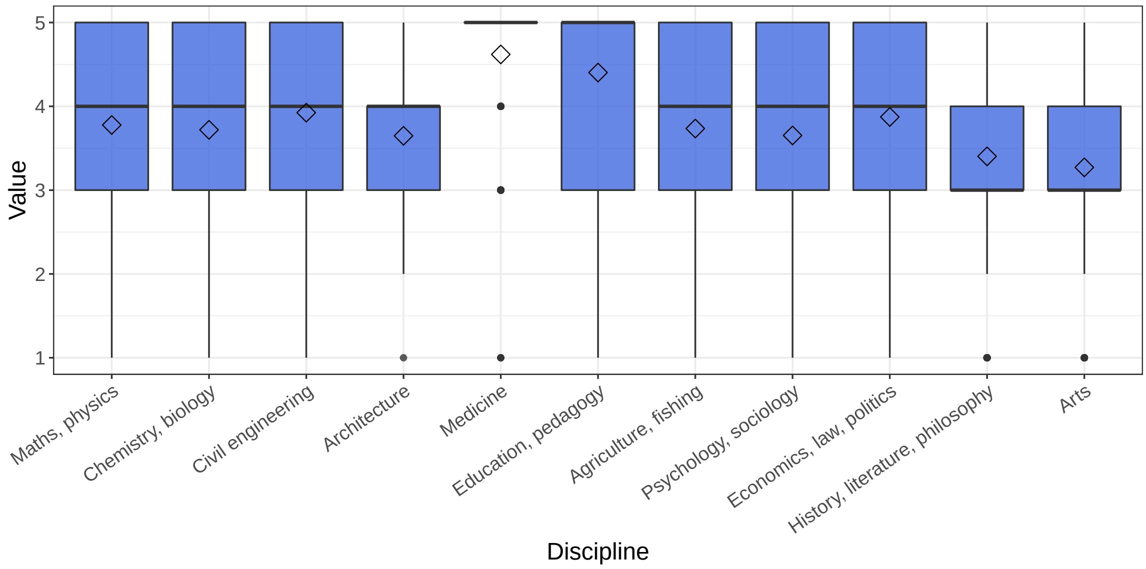

Figure 6.1. Boxplots of the answers to the question regarding the societal contribution of several areas of knowledge

It can be observed that there exist similarities in the results of certain fields. First of all, in the fields of maths and physics; chemistry and biology; civil engineering; agriculture and fishing; psychology and sociology, and economics, law and politics, the interquartile ranges are the same: Q1 corresponds to a medium importance (*value* = 3) and Q3 corresponds to a high importance (*value* = 5). However, there are respondents that attributed very low and low importance to these fields (values of 1 and 2 respectively). In all cases, the median corresponds to a high importance (*value* = 4). Among these fields, the mean is below the median value, but it is the highest for civil engineering and lowest for psychology and sociology.

Secondly, the responses for education and pedagogy range between importance of values 1 to 5. The responses differ from the previous fields in that the median and Q3 are the same, and the mean is above a value of 4.

Thirdly, similarities are also noticeable between the fields of architecture; history, literature and philosophy, and arts. In these cases, Q1 belongs to a medium importance (*value* = 3) and Q3, to a high importance (*value* = 4). In the cases of history, literature and philosophy, and arts, the median is the same as Q1, whereas in the case of architecture it is the same as Q3. In these cases, the lowest values correspond to a low importance, except for the outliers, which are at a value of 1 (corresponding to very low importance of the discipline).

Finally, the field that presents the most marked differences corresponds to the field of medicine, for which the vast majority of respondents allocated the highest social contribution, which corresponds to the value of 5.

Figure 6.1 showed the data taken individually. However, it is also interesting to see whether there exist differences in the perceptions that the respondents have depending on sex and occupation. The results disaggregated by these two variables are shown in Figures 6.2 and 6.3.

First of all, as for gender (Figure 6.2), in the fields of maths and physics; architecture; medicine; agriculture and fishing; and history, literature and philosophy the differences existing between male and female respondents are not significant in any of the statistics analysed (quartiles, mean and variance).

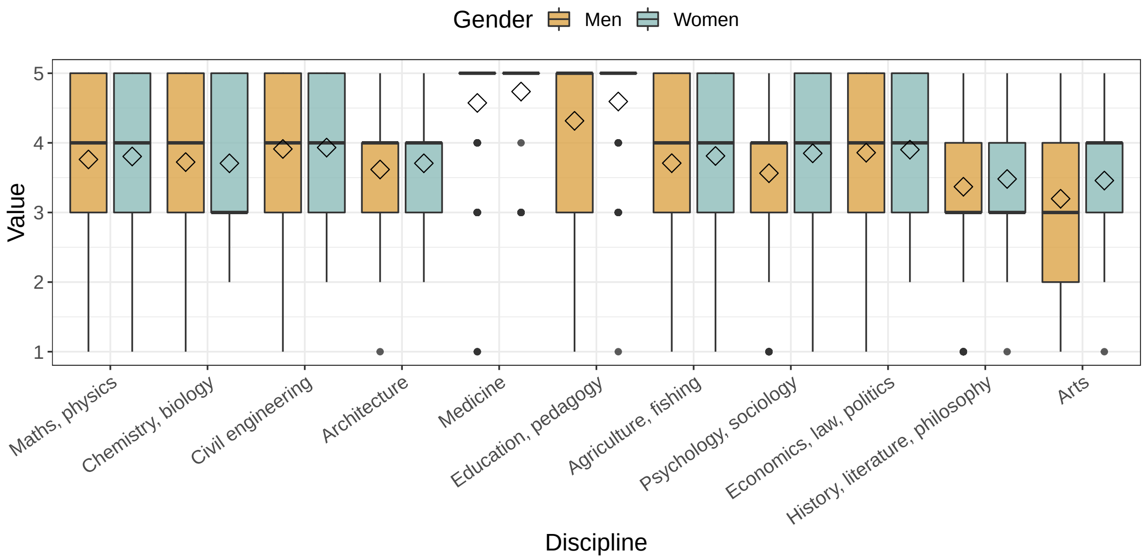

Figure 6.2. Boxplots of the answers to the question regarding the societal contribution of several areas of knowledge, disaggregated by gender

The fields that present differences between answers provided by male and female respondents are chemistry and biology; civil engineering; education and pedagogy; psychology and sociology; economics, law and politics, and arts. Among these, the greatest differences appear in education and pedagogy; psychology and sociology, and arts. Firstly, in education and pedagogy, the majority of female respondents considered that the field has a very high contribution to society to the extent that Q1, Q2 and Q3 are all located at a value of 5. On the contrary, the answers of male respondents are more spread around all the answer choices in a way in which Q1 corresponds to a medium importance (*value* = 3), and Q2 and Q3 to a very high importance (values of 4 and 5 respectively). The lowest values of the sample correspond to the minimum value.

Secondly, and differently to the previous field, the data for the field of psychology and sociology is more spread for female respondents than for male respondents. Whereas the first quartile corresponds to the minimum contribution of the field to society (*value* = 1) and the third quartile to the maximum one (*value* = 5), the data for male respondents ranges from 2 to 5, with the exception of outliers.

Thirdly, the answers given in relation to the field of arts are more spread and with a lower mean value for male respondents than for female respondents, who consider that arts have a higher contribution to society than what male respondents consider.

In order to examine whether the differences are significant, chi-square tests of independence were used. Among the disciplines analysed, a chi-square test of independence showed that there was a significant association between gender and the perceived social contribution of Psychology, $\chi^2\,(4, N = 450) = 19.1, p < .001$.

As for the differences related to the current positions of the respondents (Figure 6.3), in this case, there exist differences to a greater or lesser extent in almost all the fields. However, a first noticeable characteristic is that there is no single trend in the answers provided among different respondent groups. It can be seen that the first four disciplines represented show a decreasing trend, the next two fields (medicine and education) indicate an increasing trend, and no particular trend can be observed in the last fields.

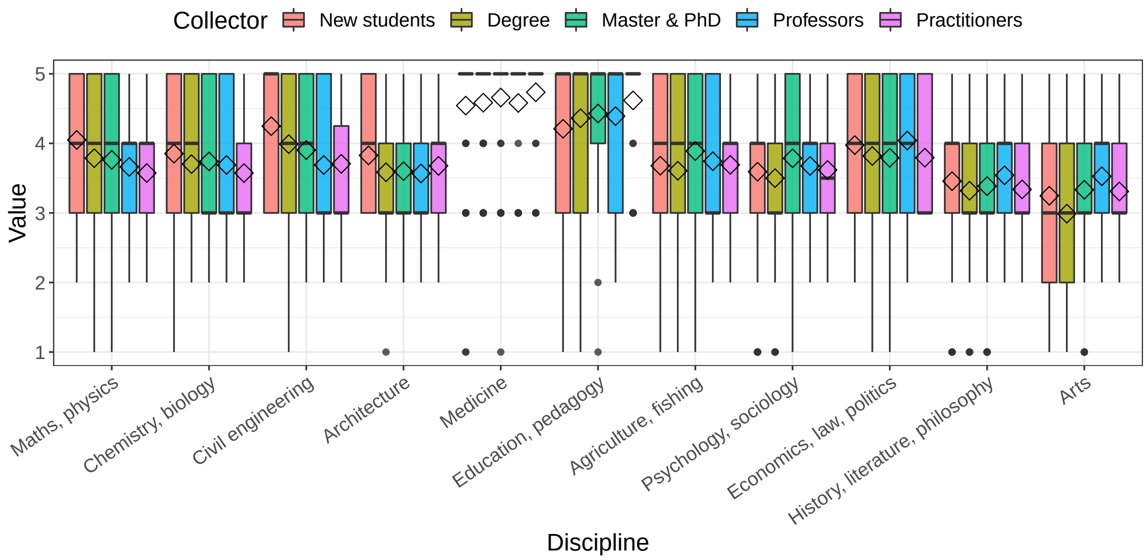

Figure 6.3. Boxplots of the answers to the question regarding the societal contribution of several areas of knowledge, disaggregated by respondent group

A field that presents very similar results across all the groups is medicine, in which again the third quartiles fall in a value of 5 and there are outliers in the possible answer choices. Apart from medicine, the statistical characteristics of the answers for the field history, literature and philosophy are as well similar. The first and third quartiles are the same for each group and correspond to the values of 3 and 4 respectively. However, there are differences as for the median value in different groups.

Chi-square tests of independence showed that there were significant differences between position and for the cases of the disciplines Maths and physics, $\chi^2\,(16, N = 450) = 33.6, p = .006$; Civil engineering, $\chi^2\,(16, N = 450) = 33.3, p = .007$; Agriculture and fishing, $\chi^2\,(16, N = 450) = 27.9, p = .03$; Psychology and sociology, $\chi^2\,(16, N = 450) = 26.7, p = .05$; and Arts, $\chi^2\,(16, N = 450) = 31.0, p = .01$.

6.2.1.2. Construct validity

Since one of the objectives of this question was to examine how the concept of the social contribution of civil engineering is perceived by different individuals, the validity of the question's construct was analysed in greater detail. In particular, the construct validity was analysed based on IRT, and through a Rasch model. The Rasch model applied was polytomous. In it, the probability of the person answering one of the response categories of an item is considered as a logistic function. This function is determined by the person's ability (which is known as the person's parameter) and the item difficulty (known as the item's parameter).

In the present case, the person's parameter is related to the person's construct of the dimension under analysis and the item's parameter is related to how easy or difficult it is to evaluate favourably that a specific field has a contribution on society.

An important consideration when working with Rasch models is the fitting of the data. In particular, it is necessary to examine whether the data fit the model. The fit of the data serves as a quality control mechanism. If the data deviated to much from the Rasch model, the causes need to be examined and decide whether the misfitting subject or item needs to be removed.

To this aim, mean-square residual summary statistics are convenient quantitative measures of fit discrepancy. Outfit (outlier-sensitive fit, see Linacre, 2002) and infit (inlier-sensitive or information-weighted fit, see Linacre, 2002) are examples of mean-square residual summary statistics. They have expectation of 1, and they can range from 0 to infinity. Infit is more sensitive to unexpected responses to items that are at the centre of the respondents' distribution, whereas outfit is more sensitive to unexpected responses to items that are at the extremes of the distribution.

Outfit and infit values that are that are higher than 1 indicate underfitting to the Rasch model; namely, the data is less predictable than what is expected by the model. Mean squares that are lower than 1 indicate overfitting to the model; this is, that the data is more predictable than the model expects. Namely, the amount of information given by the field can be well predicted from the other fields, which means that is not providing many more new information.

For instance, a mean-square statistic of 1.2 indicates that there is 20% more randomness in the data than what the model expects. On the contrary, a mean-square statistic of 0.8 means that there is a 20% of deficiency in the predicted randomness of the Rasch model. This implies that there is more ambiguity in the model. For instance, this may happen when the difficulty of an item estimated from persons with a low ability differs considerably from the difficulty of the item estimated from persons with high ability.

In addition to the previous considerations, the existence of unobserved categories also needs to be examined. An unobserved category is that one that has not been observed. In this case, the field Medicine did not have any response for category 2 (corresponding to "low contribution to society"). The inference to this is that this category must have a rather low probability of being observed. Therefore, this corresponds to a very high value for the unobserved category.

In the literature, this issue has been solved in different ways. Here, it was decided to include a dummy data record. The dummy record had responses equal to the median for each of the fields, except for medicine, in which 2 was input to solve the issue concerning unobserved variables.

Table 6.1 shows the item statistics. It can be observed that, in general, outfit and infit values do not differ significantly. The items have outfit values that are relatively more different from their infit values are Medicine, Economics, law and politics, and Psychology. Apart from this, Civil engineering, Education and pedagogy, Agriculture and fishing, History, literature and philosophy, and Arts have outfit and infit values that are above 1. For items Maths and physics, and Psychology and sociology, only one of the two statistics is above 1. Nevertheless, it needs to be noted that, in all cases, the infit statistics do not differ greatly from 1. Regarding item difficulty, it can be observed that the easiest items were Arts and History, literature and philosophy, while the hardest ones were Medicine and Civil engineering.

Item difficulty is also reflected in Figure 6.4, which shows the person-item map of the results of the Rasch analysis. The figure shows the location of the respondents' abilities as well as the item difficulties along the same latent dimension. The person parameters are shown at the top of the figure, and are located from left (least contribution) to right (highest contribution). The item difficulties are shown with solid black circles, and the thresholds of the scale used are presented through void circles.

As it can be seen, the highest item difficulty measure was for item Arts. The lowest item difficulty measure was item Medicine. The range of the item response thresholds was from -3 to 3 logits, and

Table 6.1. Item statistics of the question regarding the societal contribution of several areas of knowledge

Item		Difficulty	Outfit	t_{outfit}	p_{outfit}	Infit	t_{infit}	p_{infit}
1	**Maths, physics**	-1.06	0.996	-0.050	0.960	1.003	0.075	0.940
2	**Chemistry, biology**	-1.37	0.947	-0.913	0.361	0.955	-0.821	0.412
3	**Civil engineering**	-1.51	1.029	0.510	0.610	1.038	0.785	0.432
4	**Architecture**	-1.30	0.984	-0.263	0.792	0.983	-0.275	0.783
5	**Medicine**	-1.57	0.901	-0.619	0.536	0.996	-0.015	0.988
6	**Education and pedagogy**	-1.47	1.038	0.396	0.692	1.037	0.574	0.566
7	**Agriculture, fishing**	-0.91	1.010	0.186	0.852	1.007	0.134	0.894
8	**Psychology, sociology**	-0.70	1.006	0.124	0.901	0.997	-0.030	0.976
9	**Economics, law, politcs**	-1.13	0.981	-0.301	0.764	0.992	-0.119	0.905
10	**History, literature, philosophy**	-0.45	1.030	0.512	0.609	1.029	0.492	0.623
11	**Arts**	-0.29	1.049	0.815	0.415	1.040	0.677	0.499

they evenly covered the responses' distribution. Therefore, no gaps were reported.

In addition to the above, disordered categories are shown in the diagram with stars at the right side of the figure. As it can be observed, eight items have disordered categories (Medicine, Civil engineering, Education and pedagogy, Chemistry and biology, Maths and physics, Agriculture and fishing, and Psychology and sociology). Besides, three categories had well-functioning responses, with the item respc

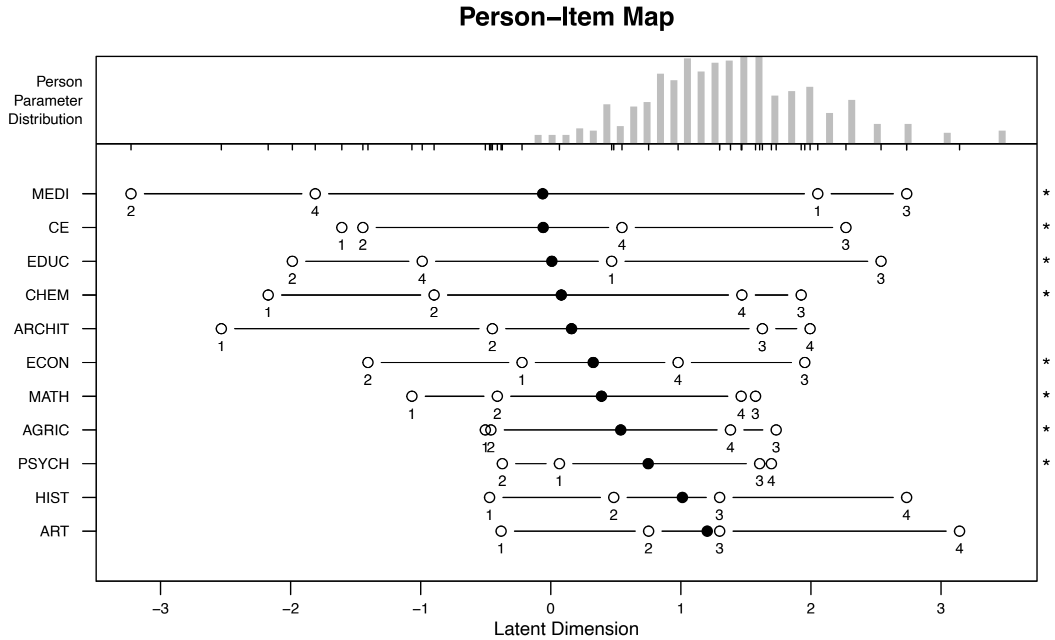

Figure 6.4. Person-item map of the question regarding the social contribution of various disciplines

Masters and Wright 1997 highlighted that disordered items do not necessarily indicate that they are problematic. To further investigate these disordered items, the option characteristic curves (OCCs) are shown in Figure 6.5 for each field. OCCs are also referred to as category probability curves. Because each field had more than two response categories, OCCs have multiple curves in the same plot. Each curve represents the probability of choosing a particular response option as a function of theta, the latent trait, which is related to the level of item difficulty. In particular, in the figure the response options are P1 to P5, each representing one category of the Likert scale that appeared in the survey.

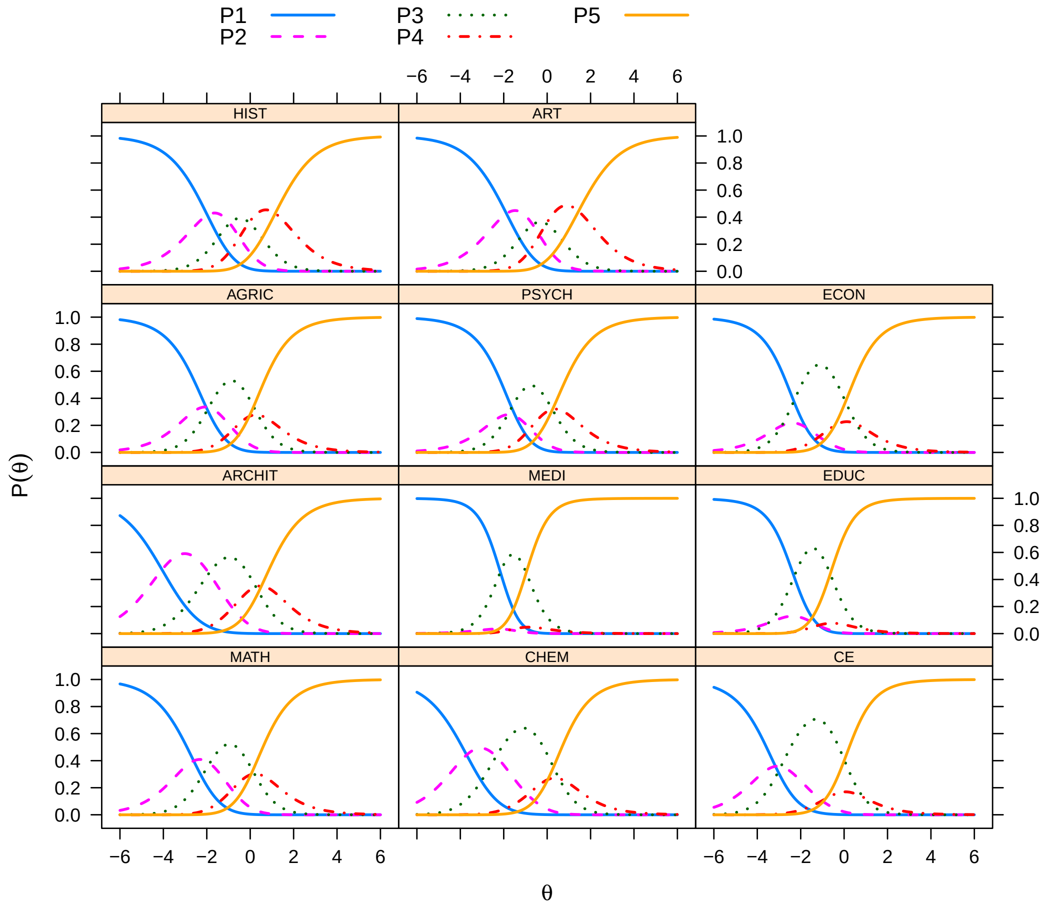

Figure 6.5. Option characteristic curves

The figures for fields Architecture, History, literature and philosophy, and Arts are examples of a well-functioning response scale with monotonic increase of the thresholds. As the difficulty increases (towards the right of the x axis), the probability of a greater degree of problem on the item also increases. Besides, all categories should be most probable at some point on the continuum. However, this did not hold for all items. In some cases, some of the scores are very flat, which indicate that they are not categories that are chosen frequently. It is the case, for instance, of Medicine and EDUC, where middle scores were not very popular among respondents.

Finally, the item response functions of each item can also be expressed through the item information curves (IICs), which display the relationship between ability and information. Figure 6.6 shows the plots of the item information functions (IIFs). These plots show the amount of information that each item can explain across different levels of the latent trait.

In an ideal situation, the information function curve would be a horizontal line at a high point of the y axis. In this context, hence, the same high amount of information would be obtained at all ability levels. However, such a function is difficult to achieve and typically the curves look like the ones in Figure 6.6, and different ability levels are estimated with differing degrees of precision.

In this situation, the apex of the curve of the IIF corresponds to the value of θ for which there is a maximum of information. According to Wu (2007), scales in which there is a wider range of values of

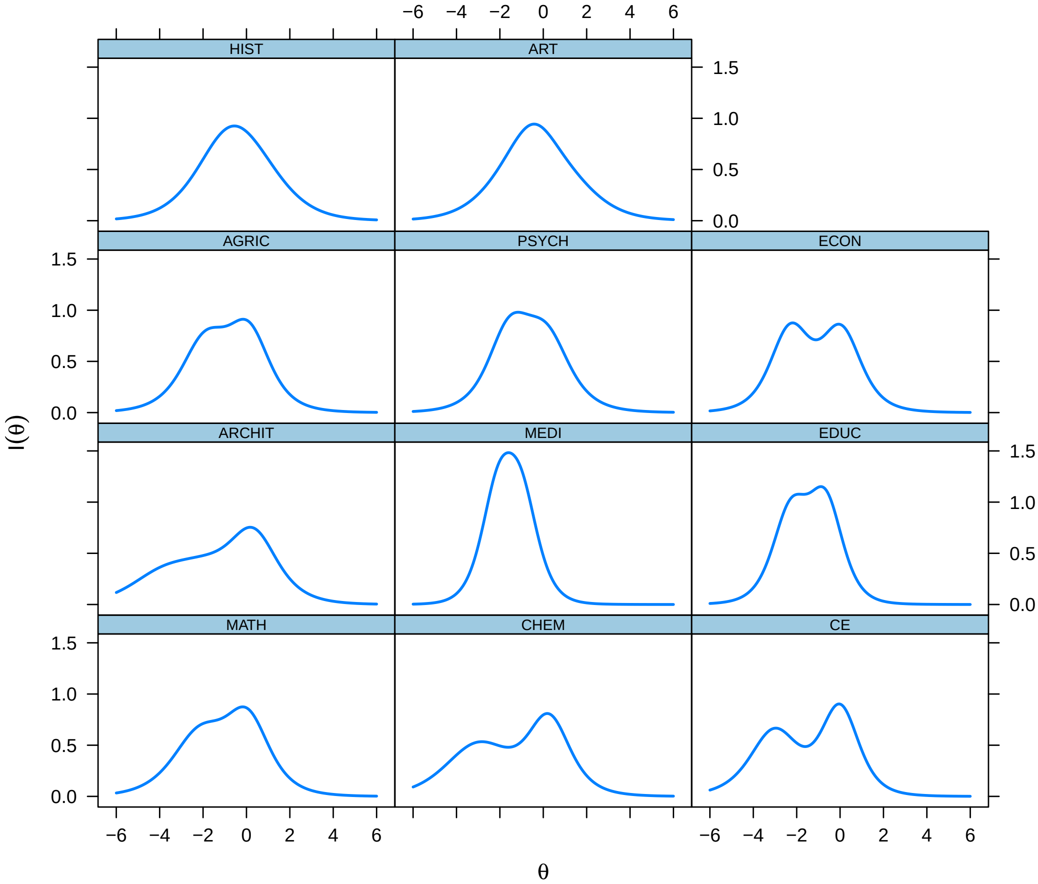

Figure 6.6. Item information functions

θ are more informative than those scales with items clustering around a single value. Hence, from the graphs it can be observed that the item Medicine is less informative because of the narrower range of the item information function. Besides, if all the IIFs are looked together, it can be seen that the whole test provides the most information for slightly-lower-than average ability levels (slightly under $\theta = 1$). However, the test does not provide much information about extremely high ability levels.

6.2.1.3. Latent variable analysis

Apart from analysing the relationships between variables, it is also meaningful to explore the latent variables existing behind the responses. It is for this reason that the Mokken scaling analysis and factor analysis were performed on the data.

The data is ordered categorical, arising from the Likert-type items of the questions. According to some authors, the analysis of the latent variables may lead to more reliable results if performed using the Mokken scaling analysis. Here, both the Mokken scaling analysis and factor analysis were used in order to examine the existence of latent variables. After this, the Rasch analysis was carried out as suggested by Wongpakaran et al. (2019).

The outcome of increasing the lower bound of H_s by increments of 0.05 is shown in Table 6.2. From $H_s = 0.05$ to 0.15 all the items formed a single scale, after which two scales were formed at $H_s = 0.20$ and four scales after $H_s = 0.25$. At $H_s = 0.30$ and 0.35 four items Did Not Scale (DNS), namely Maths and physics, Architecture, Agriculture and fishing and Economics, law and politics. Because no new information was being obtained and some items were being excluded, the final solution of the Mokken analysis was set to the lowest acceptable H_s of 0.30.

Table 6.2. Scales obtained for the question regarding the societal contribution of several disciplines

Item	$H_s = 0.05$	$H_s = 0.10$	$H_s = 0.15$	$H_s = 0.20$	$H_s = 0.25$	$H_s = 0.30$	$H_s = 0.35$
MATH	Scale 1	Scale 1	Scale 1	Scale 2	Scale 3	DNS	DNS
CHEM	Scale 1	Scale 1	Scale 1	Scale 2	Scale 3	Scale 3	Scale 3
CE	Scale 1	Scale 1	Scale 1	Scale 2	Scale 3	Scale 3	Scale 3
ARCHIT	Scale 1	Scale 1	Scale 1	Scale 1	Scale 4	DNS	DNS
MEDI	Scale 1	Scale 1	Scale 1	Scale 1	Scale 2	Scale 3	Scale 3
EDUC	Scale 1	Scale 1	Scale 1	Scale 1	Scale 2	Scale 2	Scale 2
AGRIC	Scale 1	Scale 1	Scale 1	Scale 1	Scale 2	DNS	DNS
PSYCH	Scale 1	Scale 1	Scale 1	Scale 1	Scale 2	Scale 2	Scale 2
ECON	Scale 1	Scale 1	Scale 1	Scale 1	Scale 4	DNS	DNS
HIST	Scale 1	Scale 1	Scale 1	Scale 1	Scale 1	Scale 1	Scale 1
ART	Scale 1	Scale 1	Scale 1	Scale 1	Scale 1	Scale 1	Scale 1

Before moving to a more detailed analysis of the scales, it is necessary to check whether the assumptions of the Mokken scaling analysis are satisfied. Given the above-mentioned scalability results, these assumptions were examined for the scales obtained at $H_s = 0.3$. The results of the analysis of the scalability, local independence, monotonicity and invariant item ordering of the data showed that no significant violations of the assumption were present. Hence, no item needed to be excluded of the analysis.

Having checked the assumptions, Table 6.3 shows more details on the scale obtained for a lowerbound of 0.30. The items of this question created three scales. The first scale included History, literature and philosophy and Arts; the second scale included Education and pedagogy, and Psychologt and sociology; and the third scale, Chemistry and biology, Civil engineering and Medicine. As it can be observed in the table, all the H_j values across items fall above the suggested threshold level of 0.3 for either subscale. This indicates that, in the population sample, the items are sufficiently homogeneous within their respective subscale to comprise separate scales and, therefore, to measure underlying constructs. Besides, the summary H coefficients of each scale are also higher than 0.3, which suggests that the three scales are homogeneous enough to be considered as unidimensional measures.

Table 6.3. Descriptive statistics of the items (upper panel) and the scale (lower panel)

Scale	Item	M	SD	H_j	c_{itc}
1	10	3.405 (0.048)	1.020 (0.029)	0.444 (0.05)	0.420
	11	3.277 (0.049)	1.036 (0.029)	0.444 (0.05)	0.420
	Scale			0.444 (0.05)	
	Reliability	*MS=0.635*, $\alpha = 0.592$, $\lambda = 0.592$			
2	6	4.403 (0.044)	0.931 (0.031)	0.413 (0.058)	0.304
	8	3.646 (0.049)	1.037 (0.030)	0.413 (0.058)	0.304
	Scale			*0.413 (0.058)*	
	Reliability	*MS=0.516*, $\alpha = 0.464$, $\lambda = 0.464$			
3	2	3.723 (0.044)	0.938 (0.021)	0.387 (0.041)	0.376
	3	3.918 (0.046)	0.979 (0.017)	0.38 (0.044)	0.367
	5	4.626 (0.037)	0.793 (0.041)	0.354 (0.062)	0.237
	Scale			*0.376 (0.042)*	
	Reliability	*MS=0.545*, $\alpha = 0.508$, $\lambda = 0.522$			

In particular, the following are the group of fields in which the data scaled:

- **Scale 1**: History, literature, philosophy, and Arts.
- **Scale 2**: Education and pedagogy, and Psychology and sociology.
- **Scale 3**: Chemistry and physics, Civil engineering, and Medicine.
- **No scale**: Maths and physics, architecture, agriculture and fishing, and Economics, law and politics.

As it was said, the existence of latent variables was also analysed using factor analysis. Because of the ordinal nature of the data, the analysis was performed on the polychoric correlations matrix of the data. The number of factors to extract was determined using the Kaiser-Guttman rule and parallel analysis. Both methods agreed on the fact that three factors should be extracted.

For the results presented below, an oblimin rotation was used[1]. However, it needs to be noted that the varimax rotation[2] was also applied and it was seen that the results were very similar. As for the factor extraction methods, the results shown used principal axis factoring (usually referred to as PAF) as recommended by Kahn (2006). Again, the methods unweighted least-squares (ULS) and weighted least-squares (WLS) were as well tried and it was seen that, even though the loadings of each factor varied for each method, the relative structure of the loadings remained similar. This is also reported by Worthington and Whittaker (2006).

Table 6.4 shows the loadings for each of the three factors. In the literature, researchers have proposed guidelines on how to consider factor loadings. According to Child (1990), items with a communality that is lower than 0.2 should be removed. Field (2013) recommends suppressing factor loadings that are lower than 0.3. If any item has all its loadings suppressed, then that item should be removed. According to Guadagnoli and Velicer (1988) , loadings greater than 0.4 can be considered stable. Besides, they also state that there should not be cross-loadings that are too high. This can be measured by calculating the ratio between loadings, which should not be greater than 75%.

Table 6.4. Factor loadings and communalities for the question regarding the societal contribution of several disciplines

	Factor loading			**Communality**
	1	**2**	**3**	
Maths, physics	**0.455**		0.223	0.290
Chemistry, biology	**0.574**			0.388
Civil engineering	**0.747**			0.523
Architecture	0.323	0.124	0.192	0.224
Medicine	0.307	**0.486**		0.405
Education and pedagogy		**0.740**		0.508
Psychology, sociology		**0.449**	0.231	0.318
Agriculture, fishing	0.190	0.320	0.140	0.237
Economics, law, politics	0.254	0.247	0.164	0.237
History, literature, philosophy			**0.724**	0.516
Arts			**0.632**	0.419
Proportional var (%)	12.6	10.9	10.3	

In the first calculations, in factor 1, Maths and physics, Chemistry and biology and Civil engineering all have loadings above 0.45, compared to the other fields that have loadings below 0.35. Apart from this, Maths and physics have a low loading in factor 3, whereas Civil engineering and Chemistry and biology do not. In factor 2, Medicine, Education and pedagogy and Psychology and sociology have the highest

[1] It is a type of oblique rotation. This procedure performs the rotation in a way that allows for correlation between factors. See Loehlin and Beaujean (2017) for more information.

[2] It is a type of orthogonal rotation, in which it is assumed that factors are not correlated. See Loehlin and Beaujean (2017) for more information.

loadings, which are above 0.45. Medicine also has a medium loading on factor 1, and Psychology and sociology have a low loading in factor 2. In factor 3, History, literature and philosophy, and Arts are the only fields that have high loadings, higher than 0.6, compared to the other fields.

Finally, the fields Architecture, Agriculture and fishing, and Economics, law and politics have low to medium loadings in the three factors. The fact that these three fields present these results coincides with the results obtained in the Mokken analysis, in which they did not scale for the lowest acceptable H_s. In the case of Maths and physics, which did not scale either, even though it has a medium to high loading in factor 1, it does have also the additional loading in factor 3.

Finally, in order to analyse in more detail, the latent variables behind the perceived social contribution of the disciplines, Figures 6.7 and 6.8 show the biplots of the factor analysis results. Biplots are a combination of score and loading plots. In them, the scores of each response on each principal factor are plotted using dots, together with vectors that show the loadings of each variable for each of the factors. In Figures 6.7 and 6.8, different colours have been used to illustrate gender and current position, respectively.

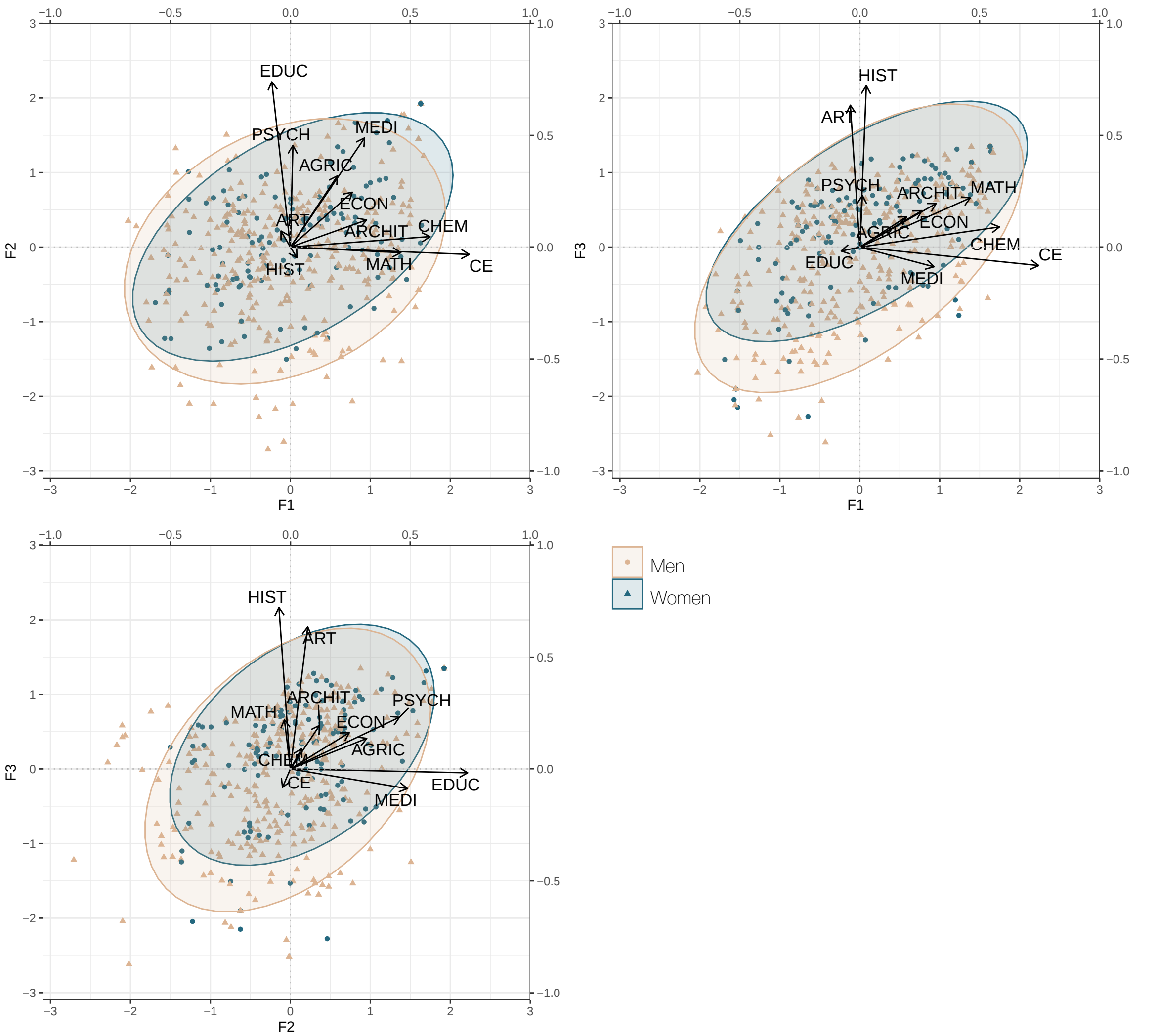

Figure 6.7. Biplots of the factor loadings for the social contribution of civil engineering disciplines, coloured by gender

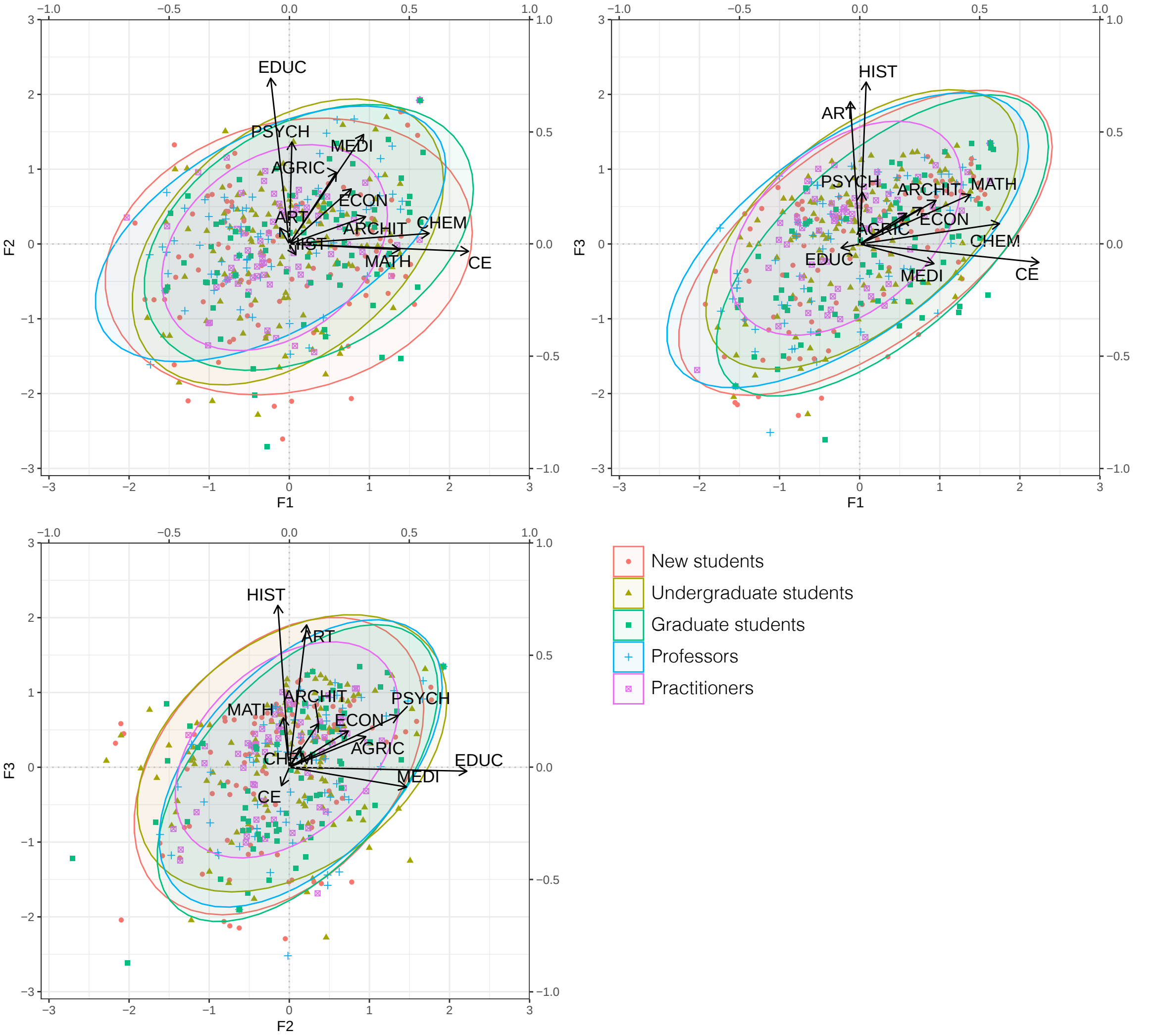

Figure 6.8. Biplots of the factor loadings for the social contribution of civil engineering disciplines, coloured by respondent group

6.2.2. Comparison between civil engineering disciplines

While the above question analysed the perceptions towards social contribution of civil engineering by comparing it to other disciplines, in this section various subdisciplines within civil engineering are contrasted. In particular, participants of the survey were asked to give a number from 1 (lowest contribution) to 5 (highest contribution) to six civil engineering fields, namely Transport, Energy technology, Urban planning, Environment technology, Water engineering, and Buildings. In what follows, first the results are described and possible associations between variables are discussed. Then, the validity of the construct analysed is examined. Finally, latent variables behind the responses are introduced.

6.2.2.1. Descriptive analysis and associations between variables

Figure 6.9 shows the perception that the respondents have towards the relative importance that each type of infrastructure has on society using boxplots.

If the data is taken individually, without considering possible respondent subgroups within the data, the item with the highest mean is water engineering ($\mu = 4.54$), followed by energy technology (μ=4.25) and environment engineering (μ = 4.25). After these, the three subdisciplines ranking lowest were transport engineering (μ = 4.20), urban planning (μ = 3.84), and buildings (μ = 3.70).

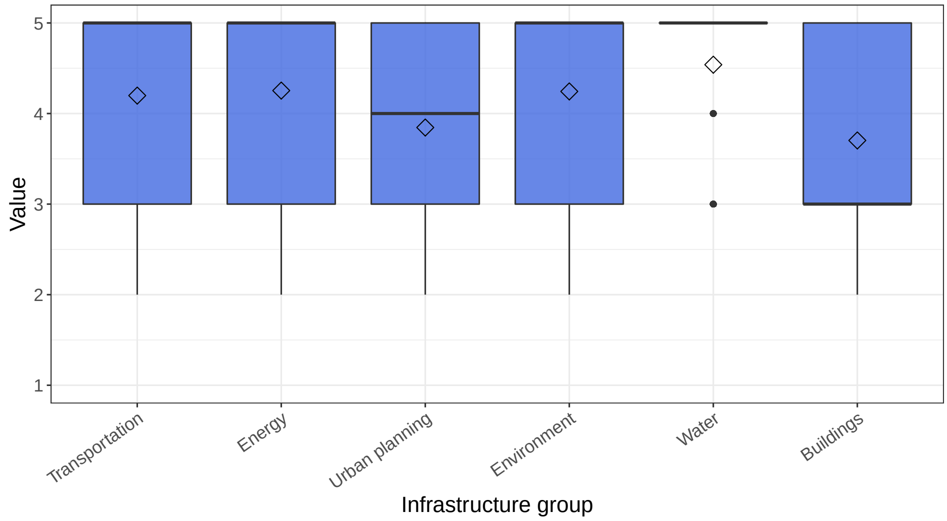

Figure 6.9. Boxplots of the answers to the question regarding the societal contribution of several subdisciplines of civil engineering

Figures 6.10 and 6.11 show the same data by gender and respondents' group. First, Figure 6.10 includes the boxplot charts of the data divided by gender. It can be seen that there are only visibly major differences in the Environmental engineering and water engineering fields. In these, the responses given by female participants allocate a higher value for the social contribution of the engineering subdisciplines. In fact, results of the chi-square tests of independence showed that the differences between gender and these two fields are significantly associated, with $\chi^2(3, N = 432) = 12.85, p = .005$ for Environmental engineering, and $\chi^2(3, N = 432) = 13.09, p = .001$ for Water engineering.

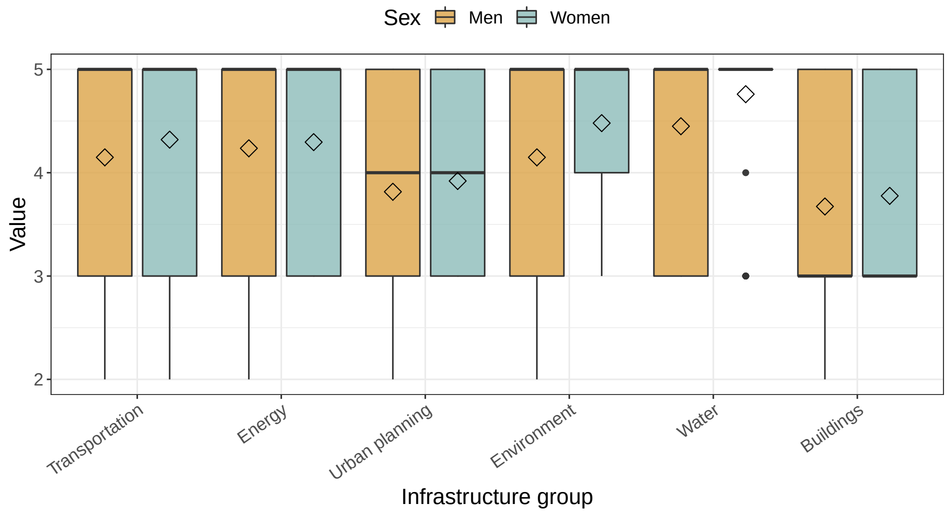

Figure 6.10. Boxplots of the answers to the question regarding the societal contribution of several subdisciplines of civil engineering, disaggregated by gender

The same responses as before are represented in Figure 6.11, where they are divided depending on the respondents' group. In this case, a first observation to be made is that, in almost every subdiscipline, the mean response tends to be lower in the boxes located more to the right; namely, for individuals in more advanced stages of their careers. The two subdisciplines in which the social contribution is considered to be lower are urban planning and buildings, whereas the one in which the responses are higher for all the cases is water engineering. This is consistent with the results of the previous section, where different disciplines were examined and the trend was decreasing for the case of civil engineering.

Results for the chi-square tests of independence showed that the variables representing the subdisciplines energy technology, urban planning, and buildings were significantly associated with the respondent group. In particular, for energy technology, $\chi^2(12, N = 432) = 22.29, p = .03$, new students were more likely to attribute higher importance (value=5) to the discipline; for urban planning, $\chi^2(12, N = 432) = 28.08, p = .005$, new students were more likely to attribute a 4 or a 5 as a response; and for buildings, $\chi^2(12, N = 432) = 26.83, p = .008$, new students were more likely to allocate a value of 4 as the social contribution of the discipline.

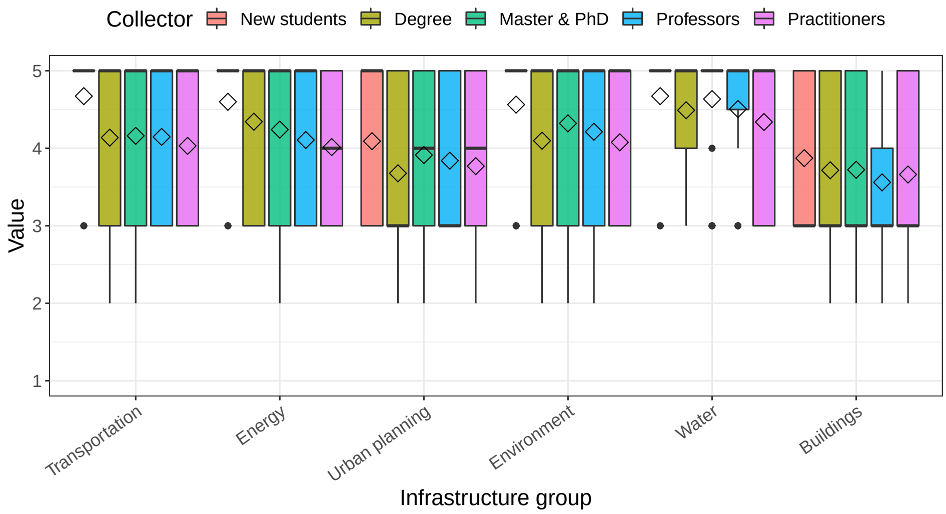

Figure 6.11. Boxplots of the answers to the question regarding the societal contribution of several subdisciplines of civil engineering, disaggregated by current position

6.2.2.2. Construct validity

As it had been done previously, the validity of the construct built in this question was examined using Rasch models. Table 6.5 shows the item statistics of the model. It can be observed that most values are close to 1, which indicates low amount of randomness in the responses. Those which are further from the value of 1 are the items energy and water technology. On the one hand, two items have item fit statistics that are above 1, transportation and urban planning. This means that these two items are less predictable than expected according to the model. On the other hand, the remaining four items have item statistics that are lower than 1, which points to the fact that they are too predictable. Nonetheless, all values are within 0.5 and 1.5, which is a common indication of a fairly adequate fit. The same results are also indicated by t_{outfit}, for which values above 0 indicate more randomness, and values below 0 may reveal higher predictability.

Figure 6.12 displays the person-item map of the model, which illustrated the location of person abilities and item difficulties respectively along the same latent dimension. The hardest items for participants to endorse are located at the right of the figure, and the easiest items for participants to endorse are at the left. It can be observed that there are no significant distances between the six items regarding the latent dimension measured, and they are all located at the positive side of the scale. This indicates that participants found it, in general, slightly difficult to endorse the scores to each of the CE disciplines.

Table 6.5. Item statistics for the question regarding the societal contribution of several subdisciplines of civil engineering

Item	Outfit	t_{outfit}	p_{outfit}	Infit	t_{infit}	p_{infit}
Transportation	1.079	0.773	0.440	1.093	1.793	0.073
Energy	0.869	-1.316	0.188	0.954	-0.884	0.377
Urban planning	1.048	0.715	0.475	1.037	0.710	0.478
Environment	0.912	-0.882	0.378	0.987	-0.237	0.812
Water	0.874	-0.748	0.455	0.987	-0.167	0.868
Buildings	0.975	-0.334	0.738	0.971	-0.502	0.616

Among the different items, the one that was found hardest to endorse was water technology, while the one easiest was buildings.

Additionally, it needs to be noted that the items that made up the question are not distributed over the whole continuum of the latent dimension. Therefore, the Rasch person-item maps, may indicate that there is no completely favourable evidence of validity to use the theoretical model for measuring the perce

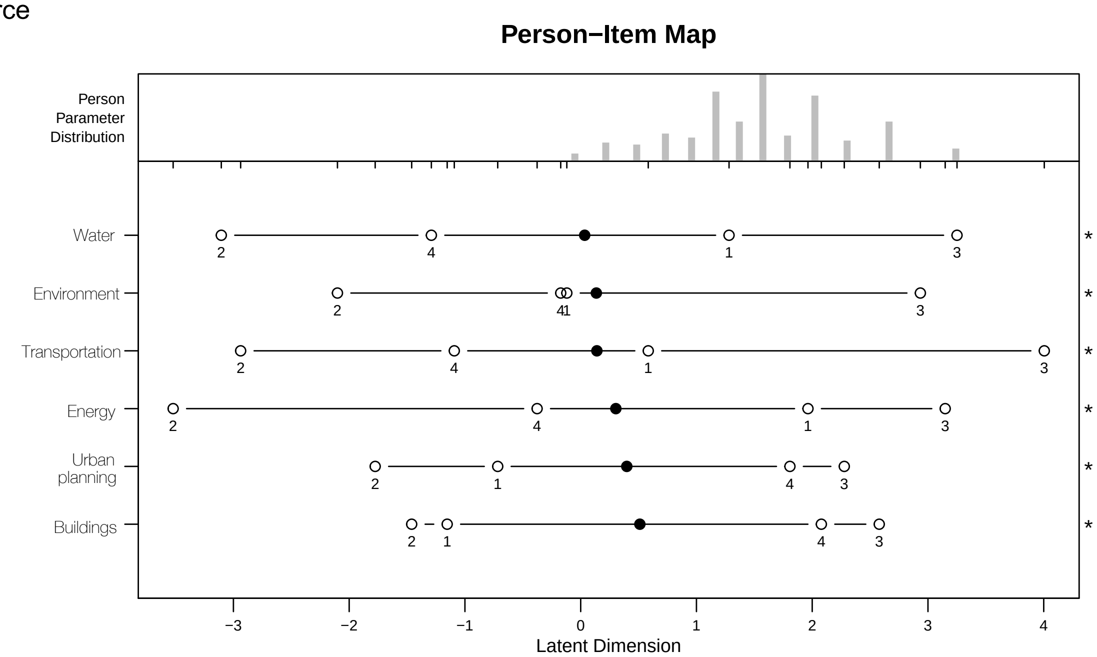

Figure 6.12. Person-item map of the question regarding the social contribution of civil engineering subdisciplines

6.2.2.3. Latent variable analysis

Finally, regarding latent variables for the responses, the results for the Mokken scaling analysis only yielded one scale. Results for the eigenvalues and parallel analyses showed the need for considering two factors in the FA analysis. Table 6.6 shows the two-factor system for the data. According to the loadings of this system, there would be a latent variable that groups the disciplines into environmental and water technology on one side, and transportation, energy technology, urban planning, and buildings on the other side.

However, as it can be seen, there is a higher number of cross-factors for multiple items. Therefore, a configuration with three factors was as well considered. The loadings of this configuration are shown in Table 6.7. As it can be seen, in this new system of factors, three groups of disciplines can be grouped.

Table 6.6. Factor loadings for the two-factor system of the social contribution of civil engineering subdisciplines

	Factor loadings		Communality
	1	2	
Environment	**0.419**	0.337	0.405
Water	**1.035**		1.056
Transportation	-0.133	**0.663**	0.394
Energy	0.284	**0.495**	0.439
Urban planning		**0.544**	0.285
Buildings	0.124	**0.502**	0.322
Proportional var (%)	22.7	22.4	

First, environment and water technologies; secondly, transportation and energy; and, thirdly, urban planning and buildings.

Table 6.7. Factor loadings for the three-factor system of the social contribution of CE subdisciplines

	Factor loadings			Communality
	1	2	3	
Energy	**0.476**	0.116	0.221	0.419
Urban planning	**0.936**			0.907
Environment	-0.194	**0.649**	0.162	0.478
Water	0.268	**0.659**		0.589
Transport			**0.655**	0.475
Buildings	0.202		**0.497**	0.365
Proportional var (%)	20.9	14.5	12.6	

To conclude the present part of the analysis, it is relevant to examine whether the latent variables explaining the responses above differ for different respondent groups. Figures 6.13 and 6.14 show the biplots of the results for the three-factor system described above, coloured by gender and by current occupation respectively. Regarding the former, it can be seen that the 95% interval of the scores of male and female respondents (represented through the ellipses) is similar when factor 2 is plotted against factor 3. Nonetheless, major differences can be found for the scores of factor 1 against factors 2 and 3, which indicates that sex has certain effects on the latent variables influencing the perception towards the social contribution of different civil engineering subdisciplines.

Regarding the biplots in Figure 6.14, which are coloured by current occupation, the major difference in the interval of the scores for each factor comes from the group of new students.

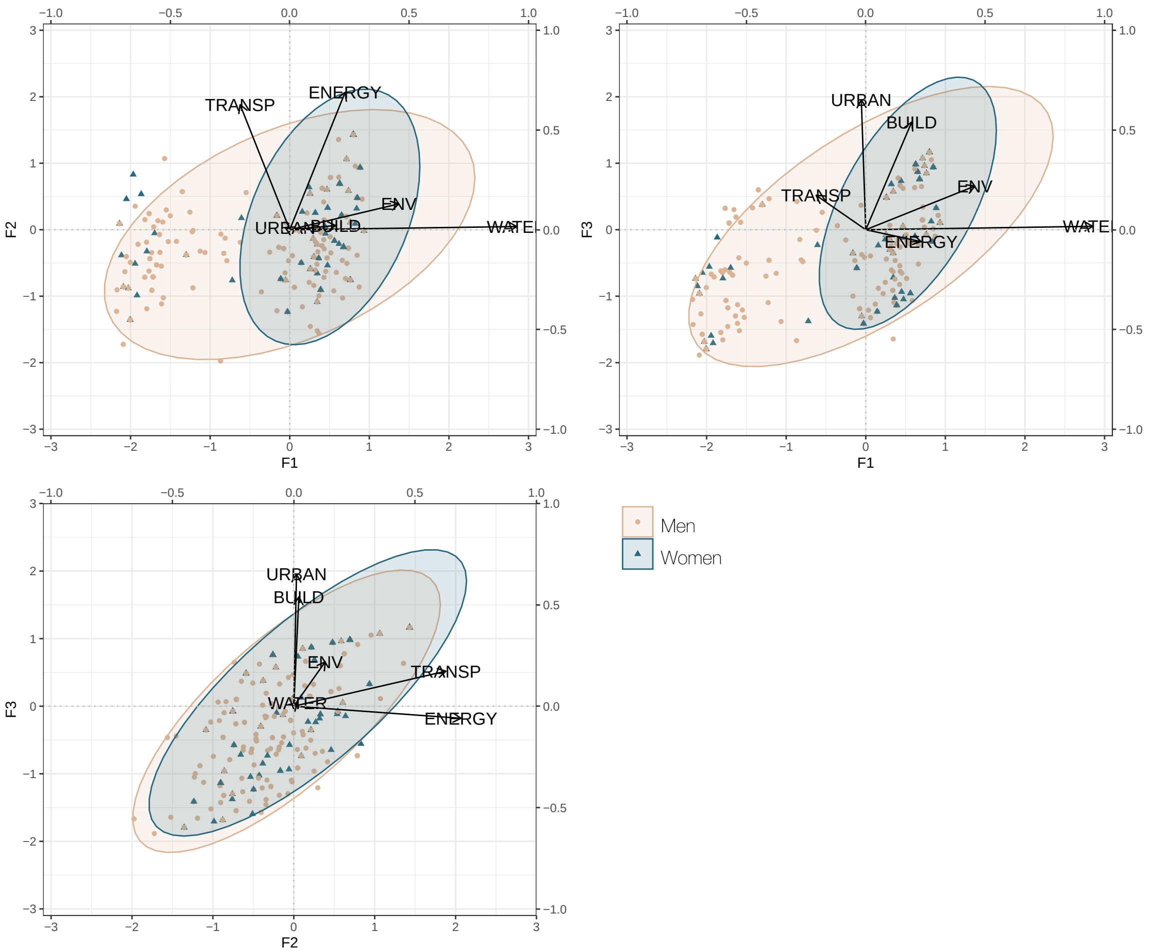

Figure 6.13. Biplots of the factor loadings for the social contribution of CE disciplines, coloured by sex

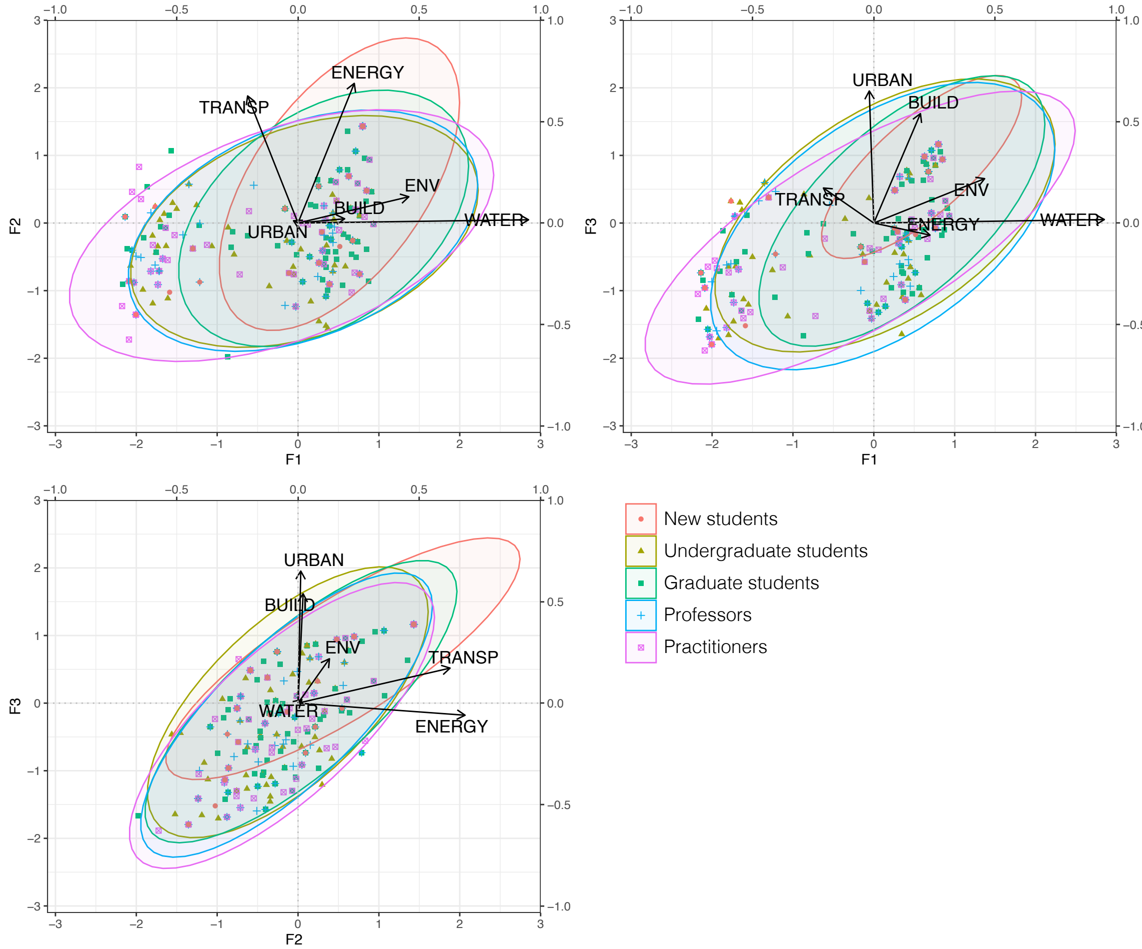

Figure 6.14. Biplots of the factor loadings for the social contribution of civil engineering disciplines, coloured by respondent group

6.2.3. Prioritisation of the social: general approximation

In the two previous subsections, respondents had to think about the social contribution of various disciplines and subdisciplines by scoring the in a scale from 1 to 5. However, it is relevant to understand what is the relative importance that they consider that the social dimension has in comparison to environmental and economic issues. This is what is studied in this subsection.

6.2.3.1. Descriptive analysis

Figure 6.15 shows a boxplot with all the responses given to the priority that should be given to each of the three pillars (economic, environmental and social), in a civil engineering project. Note that, in the y-axis, 1 and 3 correspond to the highest and lowest importance, respectively. The thicker line corresponds to the median, whereas the top and bottom horizontal lines of each plot correspond to the first and third quartiles respectively. The diamond represents the mean value of the responses.

It can be seen that the highest mean corresponds to environmental aspects (mean of 1.878), closely followed by social aspects (mean of 1.914) and finally, economic aspects (mean of 2.208). As for the quartiles, social and economic aspects both have the first, second and third quartiles located in the values of 3, 2 and 1 respectively. On the contrary, the first and second quartile of environmental aspects are located in a value of 2, whereas the third quartile is located in a value of 1.

On the one hand, these results show that environmental aspects are more commonly perceived as having a greater importance in projects and usually being prioritised in the first or the second positions in front of social and economic aspects. On the other hand, the results are more spread with regard to social and economic aspects, even though the mean is higher for the former. In order to examine where the differences come from, it is interesting to analyse the data divided in the different groups of respondents.

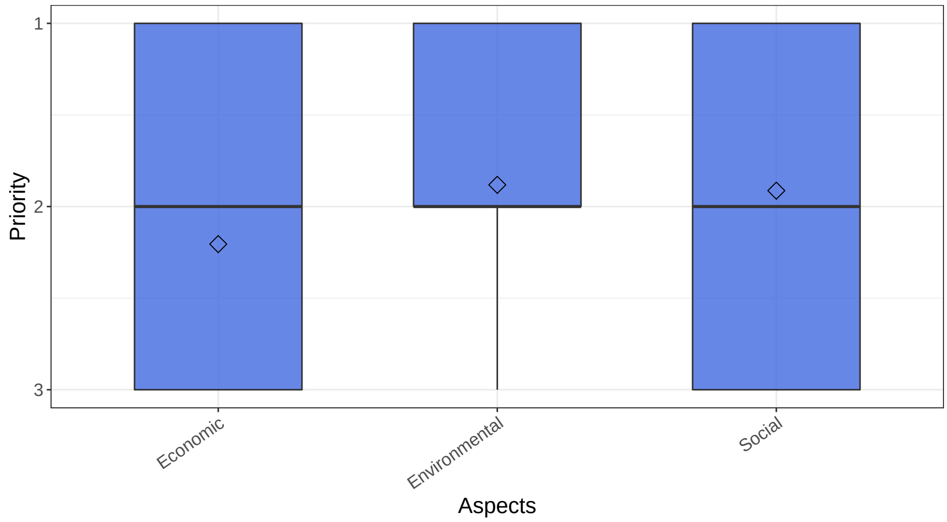

Figure 6.15. Priority (from first, 1, to last, 3) that should be given to economic, environmental and social aspects in a civil engineering project

In Figures 6.16 and 6.17, the same responses are shown grouped by gender and by the group of respondents, respectively. It can be seen that there are certain differences between respondent groups in some of the aspects analysed.

First of all, looking at the answers given by male respondents, it can be observed that there are no major differences in the values of the three quartiles among economic, environmental and social aspects. In the case of answers given by female respondents, it can be seen that there are more differences than in the case of male respondents. First of all, the results for economic and environmental aspects are less spread. In the case of economic aspects, the median of the answers is located in the lowest priority (value of 3), whereas the first quartile is located in a value of 2. In the case of environmental aspects, the median is located in a medium priority (value of 2), whereas the first quartile is located in a maximum priority (value of 1). Secondly, social aspects are still spread and the first and third quartiles range between the minimum and the maximum values.

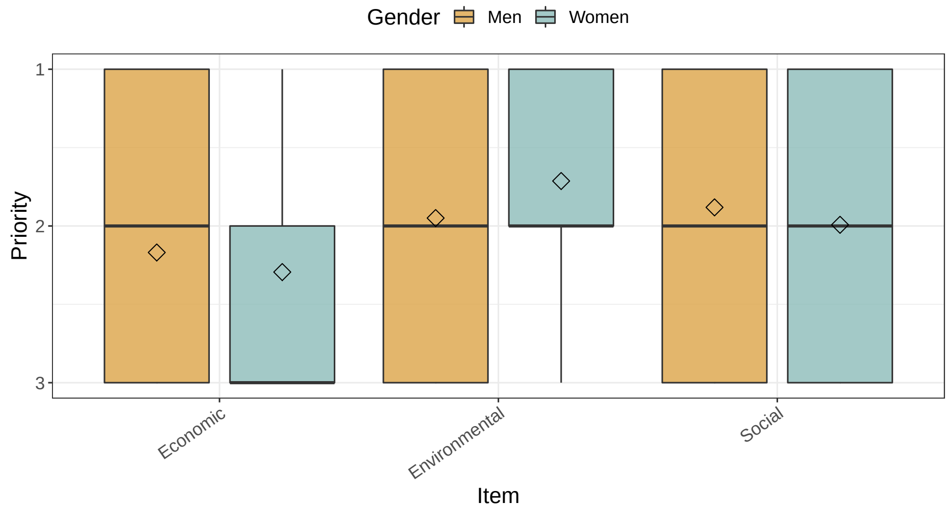

Figure 6.16. Priority (from first, 1, to last, 3) that should be given to economic, environmental and social aspects in a civil engineering project, grouped by gender

Secondly, some differences can also be observed in the answers provided by students, professors and professionals of civil engineering (Figure 6.17). For new students, economic aspects are predominantly considered to be less important than the other aspects in comparison to other respondent groups.

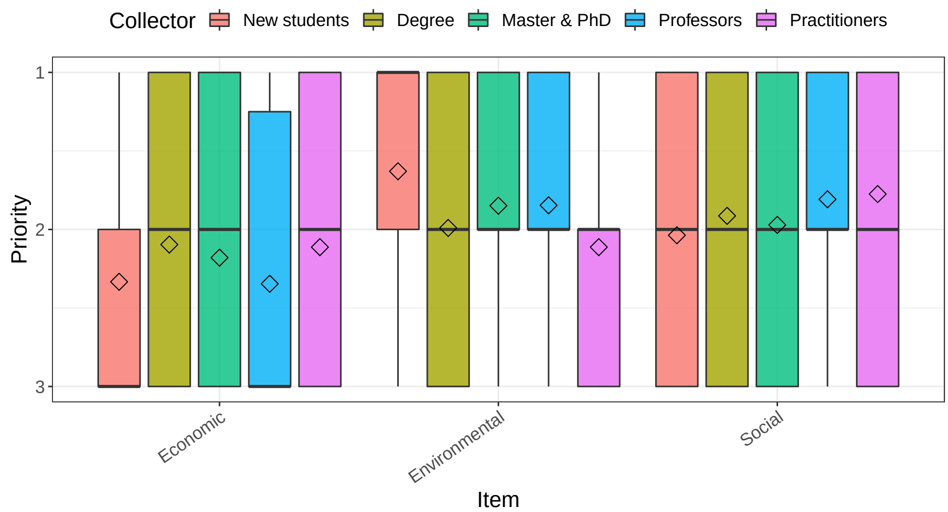

Figure 6.17. Priority (from first, 1, to last, 3) that should be given to economic, environmental and social aspects in a civil engineering project, grouped by respondent group

Undergraduate students have similar perceptions towards the prioritisation of economic and social aspects, even though the results for the latter have a higher mean. Environmental aspects are more commonly considered as the first priority, shown by the results, that are less spread and more concentrated in values of 1 and 2. Responses by graduate students are similar, but their perception towards the relative importance of environmental aspects is higher on average than for undergraduate students.

In the case of professors and researchers, environmental and social aspects present similar results, with the median and third quartile located in a value of 2, and the first quartile in a value of 1. In this case, social aspects have a higher mean than environmental aspects. The results for the economic aspects are opposed to social and environmental ones, as the median and third quartile are in a value of 3, and the first quartile is at less than 1, even though the minimum value of the answers is at 1. The mean for economic aspects in this case is specify value.

As for the answers provided by professionals, social aspects are perceived to be more important on average than environmental and economic factors. The mean value for the responses of environmental and economic aspects is similar for this group of respondents. Nonetheless, results are more spread for economic aspects than for environmental ones, where data is skewed towards the value of 3.

6.2.3.2. Associations between variables

For a more in-depth analysis of the results, statistical tests can be performed on the data. In this case, the data is ranked, which imposes restrictions on the methods that can be used. It is for this reason that the Friedman and the Kruskal-Wallis tests have been chosen to be the most appropriate tests in the present case. On the one hand, the Kruskal-Wallis test is used to analyse the effects of more than two levels of just one factor on the experimental result, whereas the Friedman test examines the effect of two factors.

The non-parametric Friedman test showed fairly significant differences among the three blocks ($\chi^2(3, N = 473) = 31.26, p < .01$). Even though Friedman test allows detecting that there are differences between items, it does not indicate where the differences are. Therefore, a post-hoc analysis is necessary. In particular, the Wilcoxon signed-rank test was used.

The post hoc Wilcoxon test with Bonferroni adjustment showed that there were significant differences between the scores for environmental aspects and economic aspects ($p < .01$) and between environmental and social aspects ($p < .01$). However, economic and social aspects did not score significantly different.

After the Friedman test and the corresponding post hoc Wilcoxon test, the Kruskal-Wallis test was used to examine possible significant differences in responses between different respondent groups. For the responses given to the economic pillar, significant associations were found between the response given and the maximum level of studies achieved. As for the environmental pillar, the three variables with which significant differences were found were gender, $\chi^2(1, N = 473) = 10.7, p = .001$, the respondent group, $\chi^2(4, N = 473) = 19.73, p < .001$, and the participation in creative activities, $\chi^2(2, N = 473) = 6.45, p = .04$. Finally, regarding the social pillar, significant differences were only found between the response given and the participation in cultural activities, $\chi^2(1, N = 473) = 4.0, p = .04$.

6.2.4. Prioritisation of the social: more specific approximation

The “social”, the “economic”, and the “environmental” dimensions are very broad categories. Therefore, to understand the previous question, the present subsection analyses in more detail how respondents would rank specific social, economic, and environmental issues in civil engineering projects.

6.2.4.1. Descriptive analysis

Figure 6.17 shows all the responses given to the priority that should be given to different aspects in a civil engineering project. The aspects that were included were: Economic profitability of the project; Labour, materials and transportation costs; Reduction of emissions (such as CO_2 or NO_x); Correct and efficient management of the generated waste; Adaptation to the social context (cultural, historic, etc.), and Enhancement of the users' quality of life. As it can be seen, there are two economic, two environmental and two social aspects.

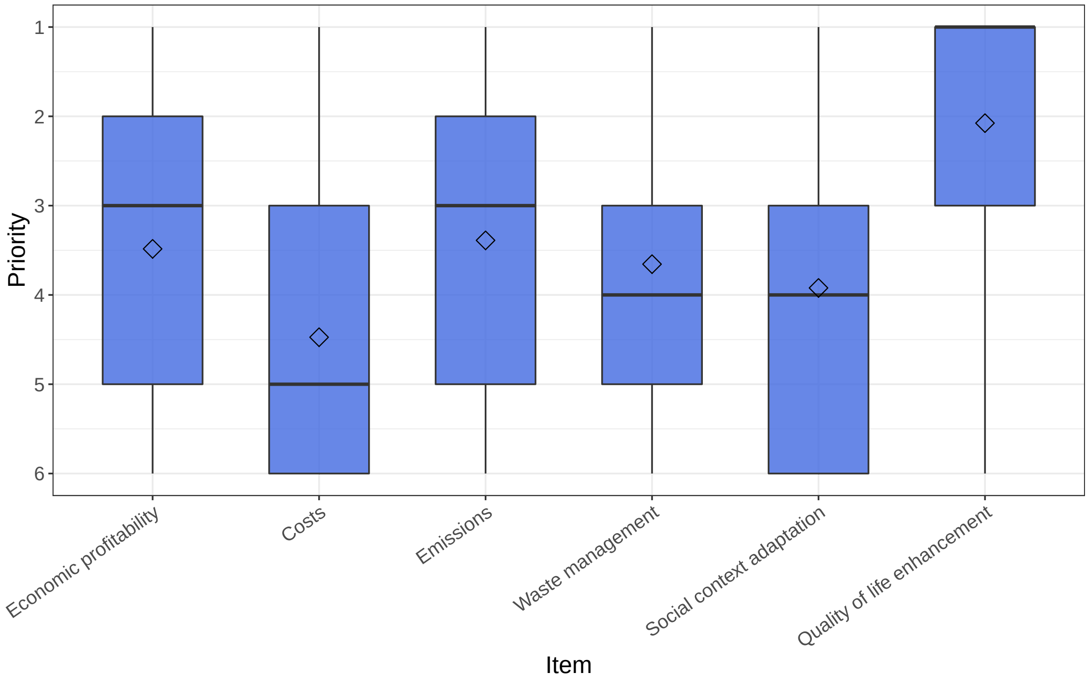

Figure 6.18. Priority (from first, 1, to last, 6) that should be given to various economic, environmental and social aspects in a civil engineering project

From the figure, it can be observed that the highest mean corresponds to Enhancement of the users' quality of life (μ = 2.073). After this, Reduction of emissions and Economic profitability of the project are the next aspects with higher means (3.389 and 3.488 respectively), closely followed by Correct and efficient management of the generated waste (μ = 3.655). Then, the following aspect is Adaptation to the social context (μ = 3.916) and finally, Labor, materials and transportation costs (μ = 4.478).

As for the quartiles, Correct and efficient management of the generated waste and Enhancement of the users' quality of life are the least spread results and present an interquartile range of 2. The remaining four aspects are equally spread, and their interquartile range has a value of 3. However, in all cases, the minimum answer given corresponds to 1 and the maximum, to 6. The order of the resulting medians, from first to last is Enhancement of the users' quality of life ($Q2$ = 1), Economic profitability of the project and Reduction of emissions ($Q2$ = 3), Correct and efficient management of the generated waste and Adaptation to the social context ($Q2$ = 4) and Labor, materials and transportation costs ($Q2$ = 5).

These results show that the importance given to each aspect is not grouped by the three sustainability pillars (economic, environmental and social). However, the data still needs to be further analysed in order to see whether such relationships exist. This is done next.

Figures 6.19 and 6.20 show the same responses grouped by gender and by the group of respondents respectively. It can be seen that there are certain visual differences between respondent groups in some of the aspects analysed.

Firstly, as for gender (Figure 6.19), the three items where major differences in the mean values and distribution of responses can be found are emissions, waste management, and context adaptation. For emissions, responses by male respondents are more spread throughout the possible responses, and the average and median are lower than for male respondents. The case is similar for the item waste management, in which both the mean and median are lower for male respondents, even though the spread of the distribution is similar for both groups of respondents.

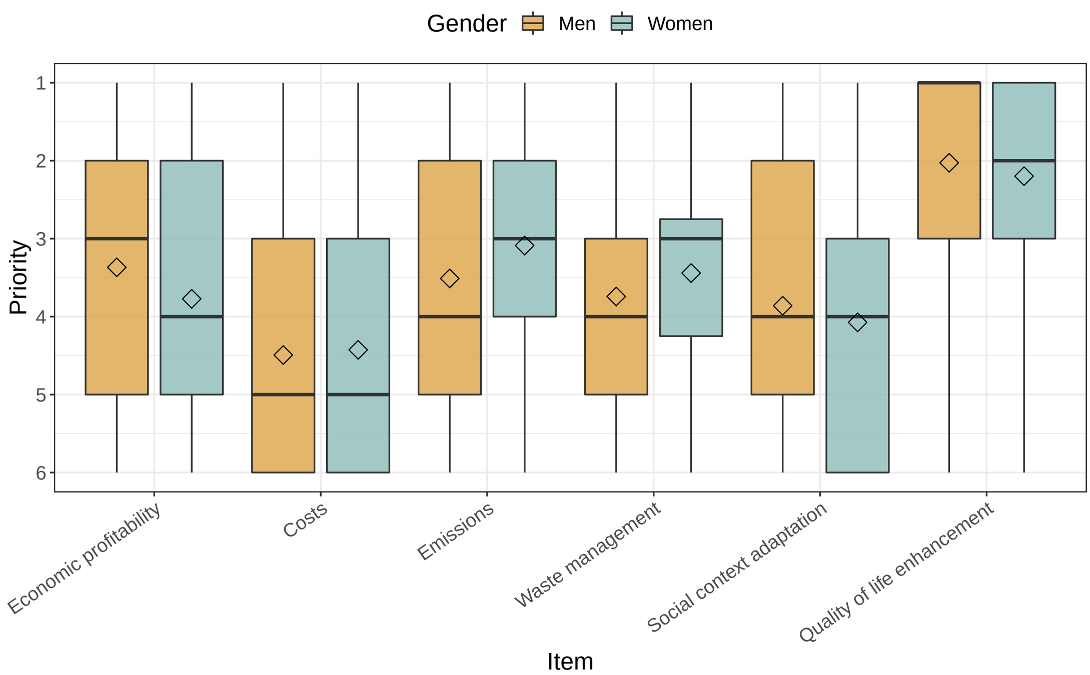

Figure 6.19. Priority (from first, 1, to last, 6) that should be given to various economic, environmental and social aspects in a civil engineering project, by gender

Secondly, as for the respondent groups (Figure 6.20), it can be observed that the distribution of responses by each respondent group is similar for each group of items. For economic items (economic rentability and costs), respondents that gave the lowest priority were professors, and among students, it was graduate students that tended to give a higher priority. Besides, responses by new students and undergraduate students were equally distributed, and with similar means and medians. For the case of the environmental items, emissions and waste management, practitioners allocated lower priorities to these items. Regarding social items, context adaptation and quality of life improvement, there were differences between students, who gave lower scores to the items, and professors and practitioners, who gave higher priority scores to the items in comparison to the three groups of students.

6.2.4.2. Associations between variables

As it was done in the previous section, the Friedman test was used to examine potential significant differences in the responses given to each item. The test showed significant differences among the six blocks ($\chi^2(3, N = 473) = 434.26, p < .001$). To see where these differences arise from the Wilcoxon signed-rank test was used.

It was seen that there exist significant differences between the responses given to most of the items, with the exception of the association between economic rentability and emissions, and between economic rentability and waste management.

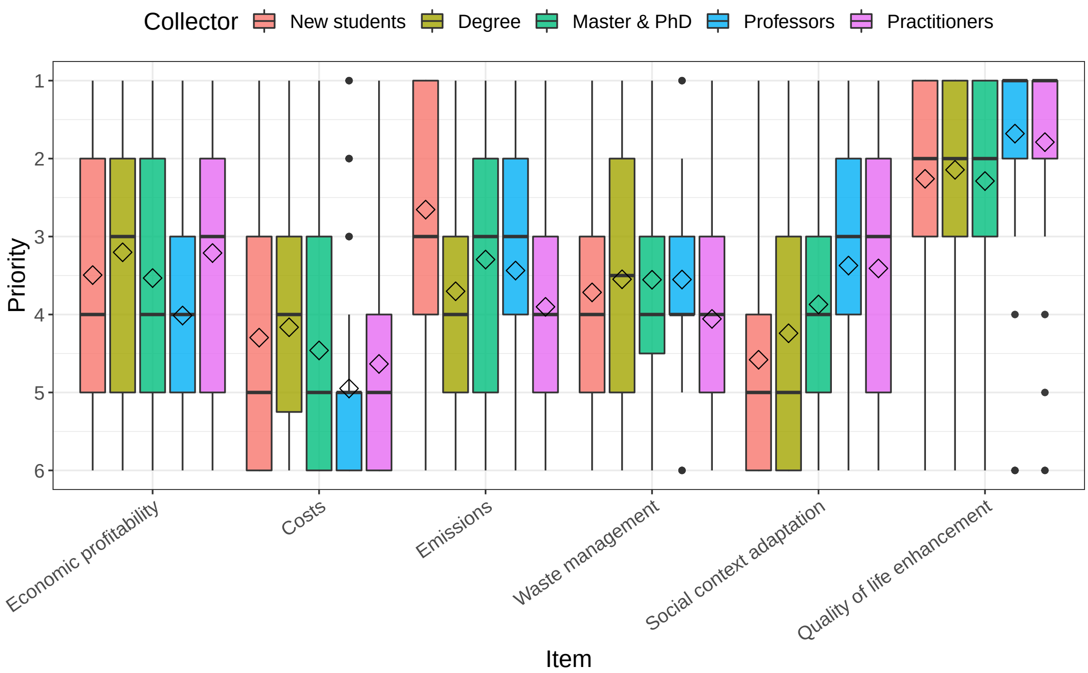

Figure 6.20. Priority (from first, 1, to last, 6) that should be given to various economic, environmental and social aspects in a civil engineering project, by current position

The Kruskal-Wallis test was performed with the objective of detecting possible differences between groups of respondents. None of the socio-demographic variables characterising the respondents that were analysed presented significant differences for each of the six items, but there were some that stood out due to the fact that the p-values resulting of the test proved significant differences for the majority of the items.

The current occupation of respondents was found to be significantly associated with all of the items, and the Wilcoxon post hoc test showed that the differences arose from the responses given by professors and undergraduate students. A second variable whose results showed significant differences with most of the items analysed was the maximum level of studies achieved. There exists a relationship between this variable and current occupation, so it is reasonable that such a result was obtained. In addition to the previous variables, the variable sex was only found to be significantly associated with the responses given to economic rentability and gas emissions. Another variable that also presented significant differences in two of the items was the participation in cultural activities, which was found to be significantly associated to the responses given to costs and context adaptation.

Given that the results of interviews reported in previous chapters indicated a possible relationship between specialisation field of professors and their perception towards the social sciences and humanities, significant differences were examined for the variable of current field of specialisation. Nonetheless, Wilcoxon tests did not show the existence of significant differences for any of the six items under study.

6.3. Perceptions regarding education

In this section, the responses given to some of the questions related to civil engineering education are discussed. This is done in three main parts: expectations by new students, perceptions by current students, and desirable areas.

6.3.1. Expectations by new students

6.3.1.1. Descriptive statistics and associations between variables

Figure 6.21 shows the responses by new students given to the question of what areas they expected to be taught in the civil engineering programme they were about to start, without disaggregation of the results. As it can be observed, the field that is believed to be the one that will be most necessary in their education is Legislation, followed by Health and quality of life and Socioeconomics. The fields that are considered to be the least needed ones are Psychology and Ethics and philosophy, chosen by less than a 12.5%. Answers to Social communications and relations and Social problems were chosen by around 12.5% in both cases. Answers to Culture and history, Politics, and Arts and aesthetics were considered as necessary by around the same proportion, 8%.

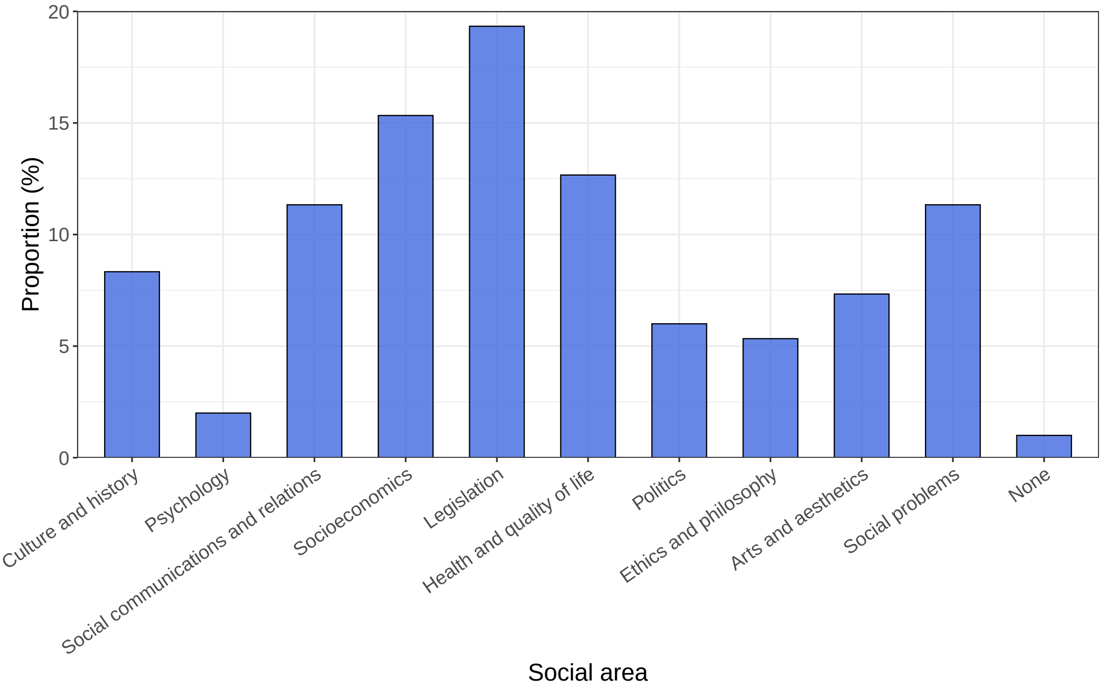

Figure 6.21. Social areas expected by new students

Figure 6.22 shows the same results disaggregated by gender. First of all, there are two categories where there are almost no differences between male and female respondents: psychology and “none of the previous”. The larger differences can be found for the items law, health, and politics. chi-square tests were performed to detect whether the differences between responses were significant. However, no significant differences were found. The proportion of subjects who reported the different social items in civil engineering programs to be necessary did not differ by gender.

6.3.1.2. Latent variable analysis

Data was also analysed to examine whether there were latent variables behind the results obtained. For this, Mokken analysis and factor analysis were utilised. Nonetheless, no relevant results were achieved with regard to this, because only one scale was obtained with H higher than 0.35. This scale included solely the items Socioeconomics, Arts and aesthetics, Culture and history, and Social communications and relations and its reliability was not high ($MS = 0.41, \alpha = 0.38, \lambda_2 = 0.43$).

Regarding the factor analysis, a scree plot was used to determine the number of latent factors to be considered. Both the eigenvalue test and the parallel analysis pointed to the need for including 4

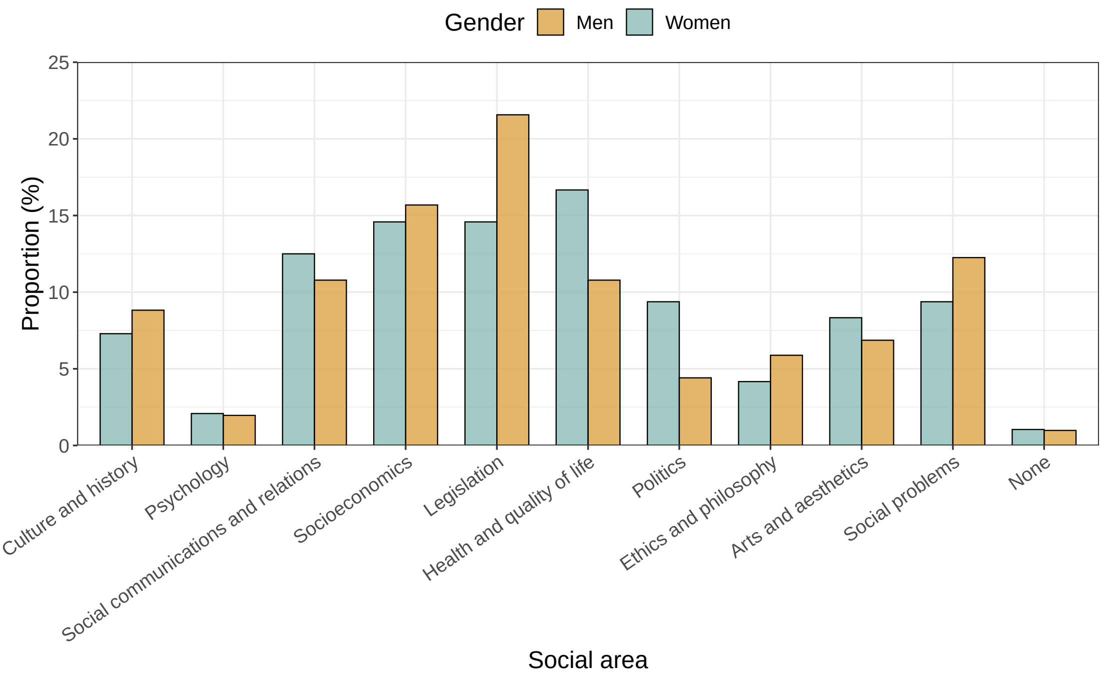

Figure 6.22. Social areas expected by new students, by gender

factors. When the analysis was implemented for this number of factors, the four factors accounted for 72.2% of the total variance. The factor loadings obtained are shown in Table 6.8.

Table 6.8. Factor loadings for data regarding perceptions of new students

	Factor loadings				Communality
	1	2	3	4	
Arts and aesthetics	**1.189**				1.415
Culture and history	**0.454**		0.395		0.365
Socioeconomics	0.396	0.357	0.273	0.239	0.528
Health and quality of life	0.365		0.187	0.301	0.299
Ethics and philosophy	0.292	-0.303	0.229	0.112	0.227
Legislation		**1.261**			1.591
Psychology			**1.145**		1.319
Politics		-0.109	0.199	**0.699**	0.587
Social problems	-0.139	0.147	-0.289	**0.686**	0.497
Social communications and relations	0.435		0.15	**0.496**	0.520
Proportional var	22.2	18.5	18.8	13.7	

As it can be seen, there were several items with cross-factor loadings, or even loadings in each factor. If items were to be grouped, one first group would include Arts and aesthetics and Culture and history with high loadings. Then, Socioeconomics, and Health and quality of life have their highest loadings for the first factor too, but have lower cross loadings in two or three other factors. A second group would integrate Legislation solely. The third group would be comprised of Psychology. Then, the fourth group would be integrated by Politics, Social problems, and Social communications and relations. These groupings represent an indication of how different social sciences and humanities areas are perceived as being connected in relation to the education that a civil engineer should have by new students.

6.3.2. Perceptions by current students

In the following subsections, the responses given by current undergraduate and graduate students are examined by examining the most relevant descriptive statistics, and analysing potential associations between variables and latent traits.

6.3.2.1. Descriptive statistics

Figure 6.23 shows the responses given by undergraduate and graduate students to the question of whether they thought that they had been taught any of the different social sciences and humanities areas during their studies. As it can be seen, the social sciences and humanities area that was answered by the highest proportion of students was Legislation, followed by Social problems. The area that was perceived as less taught during the studies was Psychology, as well as Arts and aesthetics, Ethics and philosophy and Politics.

It is also relevant to mention that there was a relatively high proportion of respondents that said that none of these social sciences and humanities areas had been taught during their studies in civil engineering (around 11%).

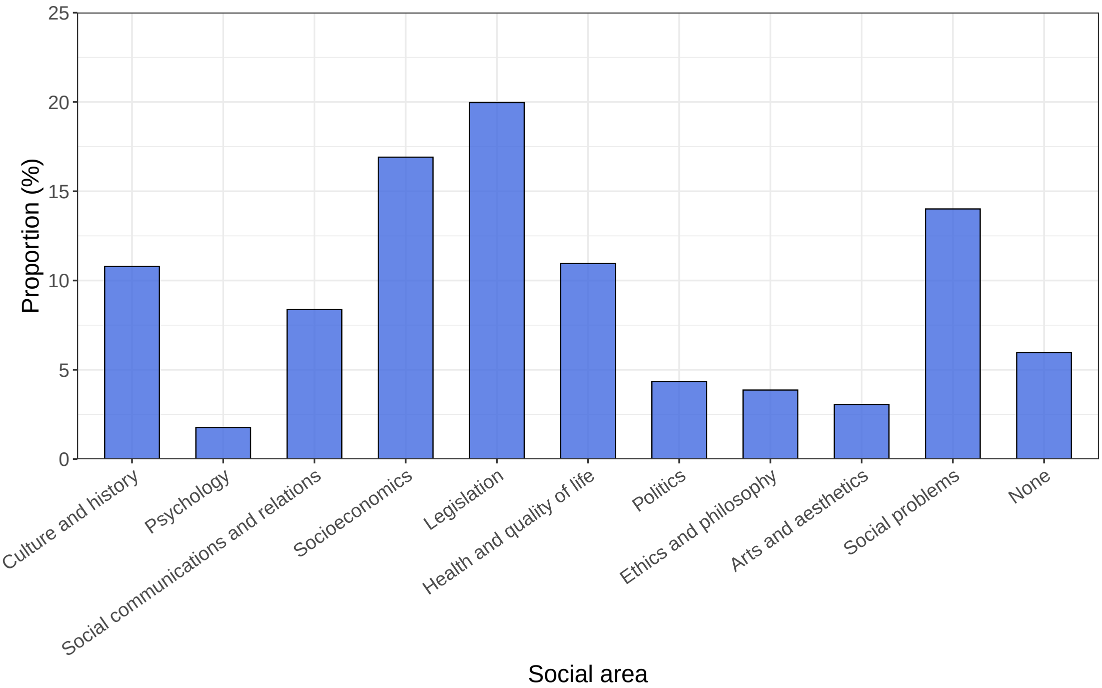

Figure 6.23. Perceptions by current students of social areas that are included

Figure 6.24 shows the results disaggregated by gender. It can be seen that no relevant differences exist between male and female respondents, except for items Culture and history, Socioeconomics and "None". chi-square tests were performed to check whether the detected differences were statistically significant, and it was found that the proportion of respondents that considered that they had been taught about Socioeconomics differed significantly by gender, with $\chi^2(1) = 5.4638, p = .019$.

In order to see how the perceptions change over time, Figure 6.25 shows the results separated between undergraduate and graduate students. Some of the items present larger differences than others. In particular, Culture and history and Social problems were answered by more graduate students. On the contrary, items Socioeconomics and Legislation were answered by more undergraduate students. Two items that stand out because very similar results were obtained for both groups are Social com-

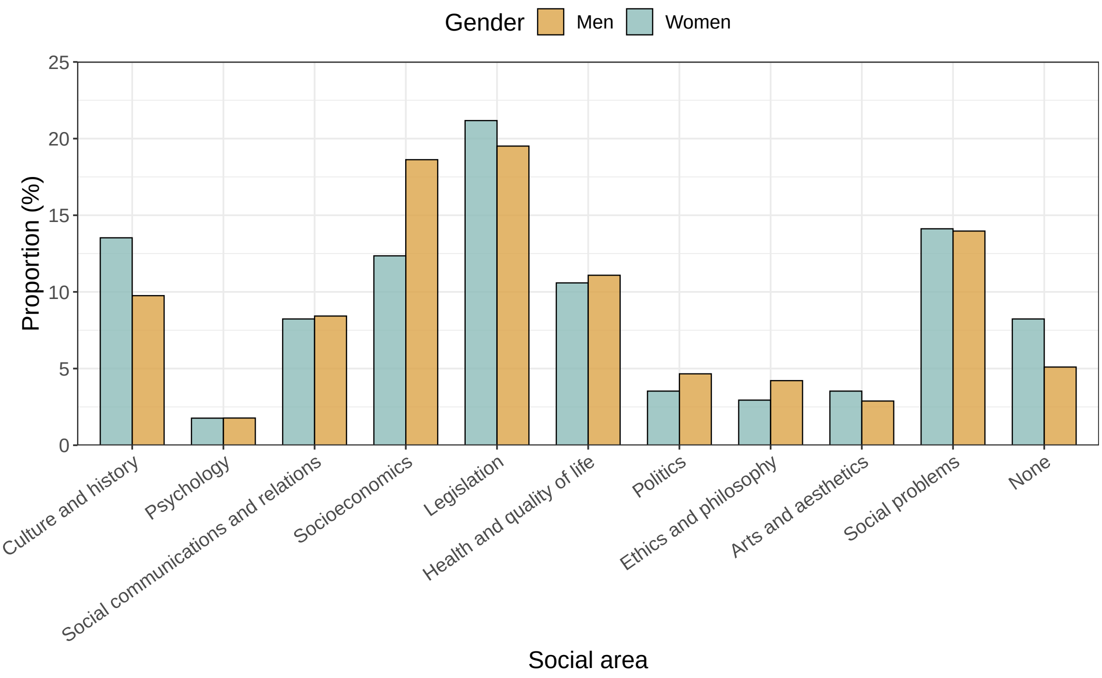

Figure 6.24. Perceptions by current students of social areas that are included, by gender

munications and relations and Health and quality of life.

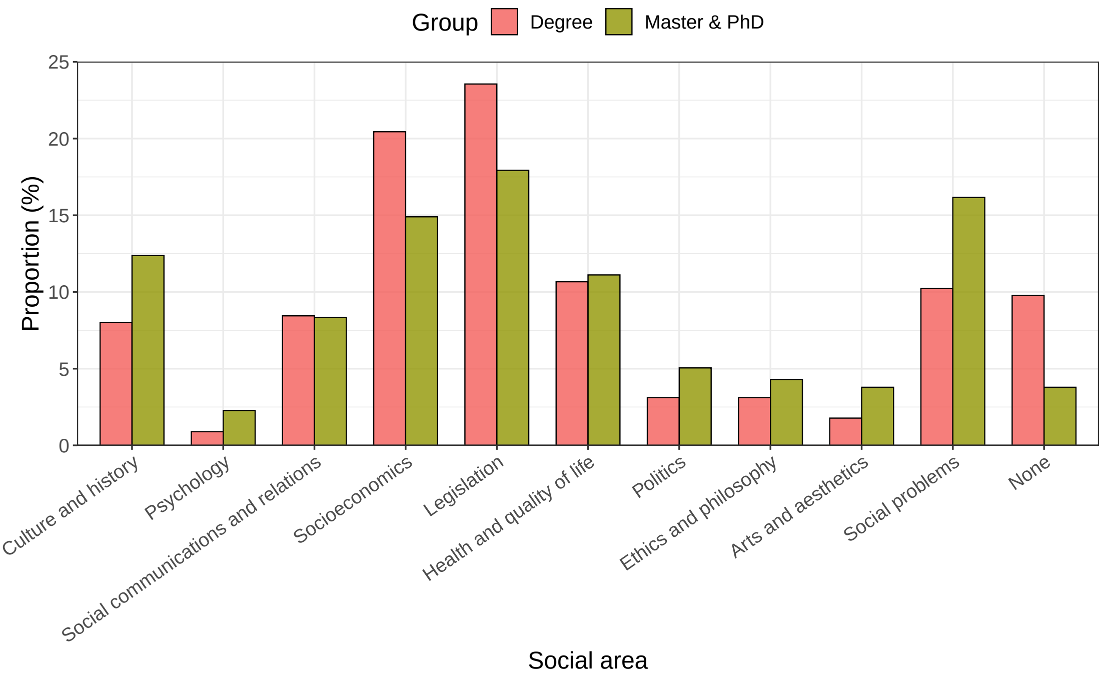

Figure 6.25. Perceptions by current students of social areas that are included, by occupation

6.3.2.2. Associations and latent variable analysis

Apart from the descriptive analysis above and the associations between variables, Mokken scaling and factor analysis were used to detect any potential latent variable. First, as for Mokken scaling, the results of the analysis yielded 3 different scales with $H_i > 0.35$. The results of increasing by 0.05 the lower bound are shown in Table 6.9.

Table 6.9. Scales obtained for data regarding perceptions of current students

Item	$H_s = 0.05$	$H_s = 0.10$	$H_s = 0.15$	$H_s = 0.20$	$H_s = 0.25$	$H_s = 0.30$	$H_s = 0.35$
CULT	Scale 1	Scale 1	Scale 1	Scale 1	Scale 1	Scale 1	Scale 1
PSYCH	Scale 1	Scale 1	Scale 1	Scale 1	Scale 1	Scale 1	Scale 2
COM	Scale 1	Scale 1	Scale 1	Scale 1	Scale 1	Scale 1	Scale 2
ECON	Scale 2	Scale 2	Scale 2	Scale 2	Scale 2	Scale 2	DNS
LAW	Scale 2	Scale 2	Scale 2	Scale 2	Scale 2	Scale 2	Scale 3
HEALTH	Scale 1	Scale 1	Scale 1	Scale 1	Scale 2	Scale 3	DNS
POLIT	Scale 2	Scale 2	Scale 2	Scale 2	Scale 2	Scale 2	Scale 3
ETHICS	Scale 1	Scale 1	Scale 1	Scale 1	Scale 1	Scale 1	Scale 2
ART	Scale 1	Scale 1	Scale 1	Scale 1	Scale 1	Scale 1	Scale 1
PROB	Scale 1	Scale 1	Scale 1	Scale 1	Scale 1	Scale 3	Scale 2

Second, regarding FA, the parallel and eigenvalue tests indicated that 3 factors were necessary for the factor analysis. The consideration of 3 factors yielded a system which accounted for 54.6% of the total variance. If one more factor was considered, the total variance of the system rose to 66.1%. Nonetheless, this change generated more cross-loadings, and the highest loading of some of the items decreased to values lower than 0.5.

The loadings for each factor are presented in Table 6.10. Except for item Health and quality of life, all items had one loading higher than 0.5, which is a criterion to assess the validity of the constructs according to Hair et al. 1998. Items Psychology, Social communications and relations, ETHICS and Social problems scored highly in the first factor, whereas items Culture and history and Arts and aesthetics scored in the second factor, and Socioeconomics, Legislation and Politics had high scores for the third factor. Item Health and quality of life, had loadings in the three factors, and all of them had values below 0.4.

From the results of the Mokken scaling and FA it can be seen that the groups of factors obtained were similar for both latent variable analysis methods, with the exception of item Socioeconomics, which did not scale in Mokken. Item Health and quality of life did not scale in Mokken and did not reach a factor loading above 0.5 for the FA.

Table 6.10. Factor loadings for data regarding perceptions of current students

	Factor loadings			**Communality**
	1	**2**	**3**	
Psychology	**0.792**			0.641
Social communications and relations	**0.769**		-0.168	0.582
Social problems	**0.625**	-0.109		0.351
Ethics and philosophy	**0.559**	0.220	0.321	0.683
Health and quality of life	0.358	-0.106	0.303	0.270
Culture and history	0.174	**0.915**	0.118	1.029
Arts and aesthetics	-0.139	**0.940**	-0.125	0.820
Legislation	-0.131		**0.813**	0.615
Socioeconomics			**0.549**	0.352
Politics	0.195		**0.522**	0.380
Proportional var	0.216	0.181	0.149	

6.3.3. Desirable social sciences and humanities areas

Up to this point of the chapter, the discussion regarding the contents of civil engineering programmes has been carried out on the basis of the perceptions by students. In previous chapters, the responses by professors to what social sciences and humanities areas they think they include in their subjects was also analysed. In addition to these questions, all the respondents were asked to answer what areas of social sciences and humanities they believed should be taught to civil engineering students. The responses given to this question are presented in Figure 6.26.

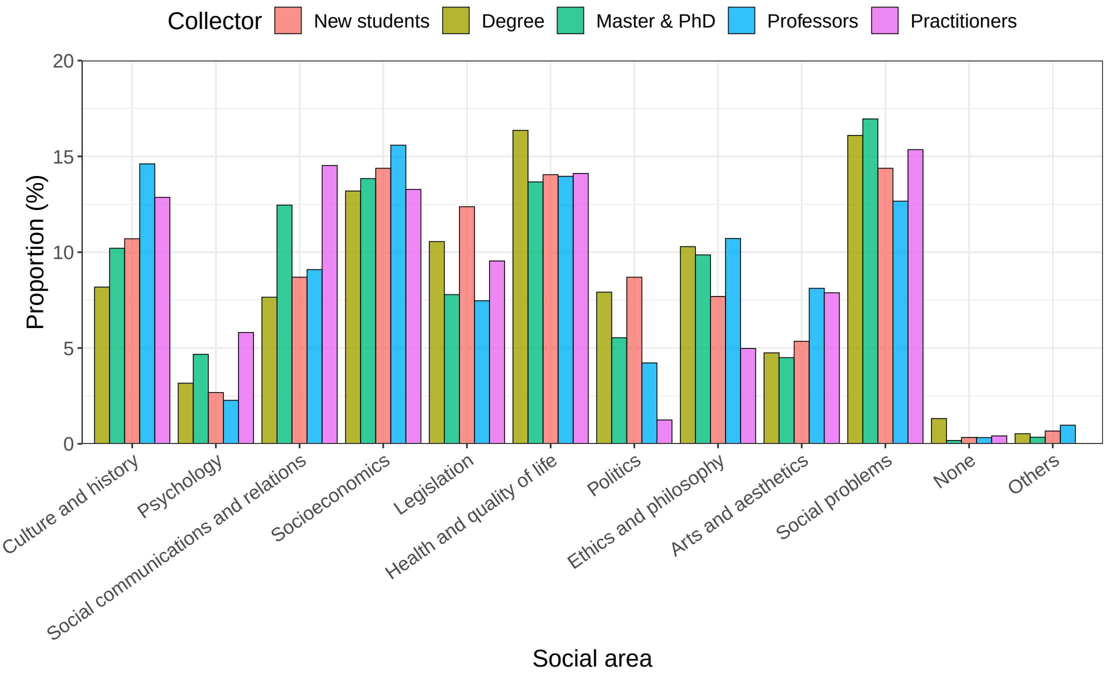

Figure 6.26. Responses to the question of what areas should be taught in CE education programmes, by respondent group

6.4. Social competencies needed

This final section of the present chapter examines perceptions towards social competencies in the context of civil engineering. The concept of competency was used for the first time by Selznick 1957 in the context of enterprises referring to a set of activities that companies carry out to perform better than other similar companies. Since then, several authors have contributed to understanding this construct (Bryson et al., 2007). In general, authors agree that there is a connection between competencies and effective professional performance (Spencer and Spencer, 1993). Sandberg (2000) referred to competency as that collection of attributes that workers utilise to carry out their tasks successfully. As Dubois (1998) describes, this collection of attributes can include knowledge, skills, or traits.

Several reports and articles have emphasised the need for engineers to foster social competencies. For instance, the Barcelona Declaration, which was settled at the 2nd International Conference of Engineering Education for Sustainable Development (for Sustainability, 2004), defined seven critical skills that engineers had to possess to face current society's problems. In a similar vein, the Shanghai Declaration on Engineering and the Sustainable Future (UNESCO, 2004) defined the challenges currently faced by engineers, described their mission, and responsibility and commitment. In addition to for Sustainability (2004) and UNESCO (2004), many publications and declarations have highlighted, to a lesser or greater extent, the need for engineers to foster their commitment to society. Other declarations are

ASEE (2010) and UNESCO et al. (2019).

Despite the above, the social competencies needed by engineers are not clearly specified in the previous documents, and only defined in general terms. In order to study these social competencies, they are classified in this thesis into transversal and technical social competencies or skills. First of all, transversal skills have also been referred to in the literature as transferable skills, or generic competencies (Succi and Canovi, 2020). Some authors refer to them as “soft skills” (Hendriana, 2017, Idrus et al., 2014). Webber et al. (2010) defined such skills as “the interpersonal, human, people, or behavioural skills needed to apply technical skills and knowledge in the workplace”.

Secondly, technical social skills refer to skills that arise from specific knowledge and are generally obtained through a combination of education and professional training. They are considered to be easier to quantify. In the literature, this sort of skills is sometimes referred to as “hard skills” (Hendriana, 2017). The use of the terms “soft” and “hard” skills may indicate some kind of inferiority of the former with respect to the latter. Here, the conceptual framework described in Chapter 3 is used to define the different dimensions of technical social competencies, as shown in Table 6.11. The transversal competencies included are the ones in Table 6.12. The tables include the abbreviations used in this section, and a general description of what they entail.

Table 6.11. Technical social competencies

Competency	Abbreviation	Description	Reference
Culture and history	CULT	Cultural and historical context of projects and their communities	Li et al. (2020)
Psychology	PSYCH	Human behaviour and social perceptions	Vale (2014)
Social relations	COMM	Interaction and communication between people	Ballinas-Gonzalez et al. (2020), Carlson and Wong (2020)
Socioeconomics	ECON	Economic activity and related social processes	Andersen (2004), Vesilind (2001)
Legislation	LAW	Legal matters	Brambila-Macias and Sakao (2021), Cooper and Ashurst (2011)
Politics	POLIT	Political context, policy making, governance	Vesilind (2001)
Health and quality of life	HEALTH	Physical and mental health, and ability to enjoy normal life activities	Kudngaongarm and Sujivarakul (2011), Zitomer et al. (2003)
Arts and aesthetics	ART	Beauty, taste, visual appearance	Weinstein et al. (2006)
Social problems	PROB	Conflicts, poverty, inequality...	Ballinas-Gonzalez et al. (2020), Vale (2014)
Ethics and philosophy	ETHICS	Justice and moral values or principles	Taajamaa et al. (2018), Tharakan (2020), Vesilind (2001)

Table 6.12. Transversal social competencies

Competency	Abbreviation	Description	Reference
Informatics	INFORM	Ability to utilize computers and technology efficiently	Perdigones et al. (2014)
Communication (written and verbal)	COM	Ability to present one's work both to professionals and lay audience	Cooper and Ashurst (2011), Enshassi and Hassouna (2005)
Conflict resolution	CONFL	Withstand, endure and resolve arising conflicts	Nguyen (1998)
Creativity and innovation	CREAT	Creative and innovative thinking, design and problem solving	Nguyen (1998), Rugarcia et al. (2000)
Data analysis	ANALY	Ability to analyse and interpret data	Shuman et al. (2005)
Flexibility and adaptability	FLEX	Capacity to adapt to change.	Enshassi and Hassouna (2005), Perdigones et al. (2014)
Interpersonal skills	INTER	Ability to interact with other people.	Enshassi and Hassouna (2005), Martin et al. (2005)
Languages	LANG	Improved command of foreign languages.	Nguyen (1998), Rugarcia et al. (2000)
Maths and Physics	MATH	Ability to apply knowledge of STEM	Enshassi and Hassouna (2005), Shuman et al. (2005)
Problem solving	PROB	Critical thinking for problem solving	Perdigones et al. (2014)
Teamwork	TEAM	Ability to engage effectively and productively in team-working.	Perdigones et al. (2014)

6.4.1. Social technical competencies

6.4.1.1. Descriptive analysis

The results of the question on technical social competencies are graphically shown in Figure 6.27. The figure shows boxplots of the results, grouped according to current occupation. Each group is represented by a different colour. Black dots represent outliers, the beginning and ending of the vertical lines represent the minimum and maximum values, respectively. The limits of the boxes depict the first and third quartiles, the wider black line is the median, and the diamonds symbolise the means.

As it can be seen, the knowledge areas that were considered, on average, most frequently needed were Legislation ($\mu = 4.33$), Socioeconomics ($\mu = 3.95$), and Politics ($\mu = 3.87$). The ones that had the lowest average responses were Arts and aesthetics ($\mu = 3.00$), Ethics and philosophy ($\mu = 3.07$), and Culture and history ($\mu = 3.24$). Nonetheless, if these averages are taken for each respondent group, important differences can be found as shown graphically in Figure 16.27, as well as in the chi-square tests of independence as will be described next.

6.4.1.2. Associations between variables

Figures 6.28 and 6.29 show the same results disaggregated by gender and current occupation, respectively. On the one hand, regarding gender, it can be seen that there are no major differences between both respondent groups, except for the cases of Socioeconomics and Social problems. For the first, Socioeconomics, male respondents attributed in average a lower need for knowledge in such area,

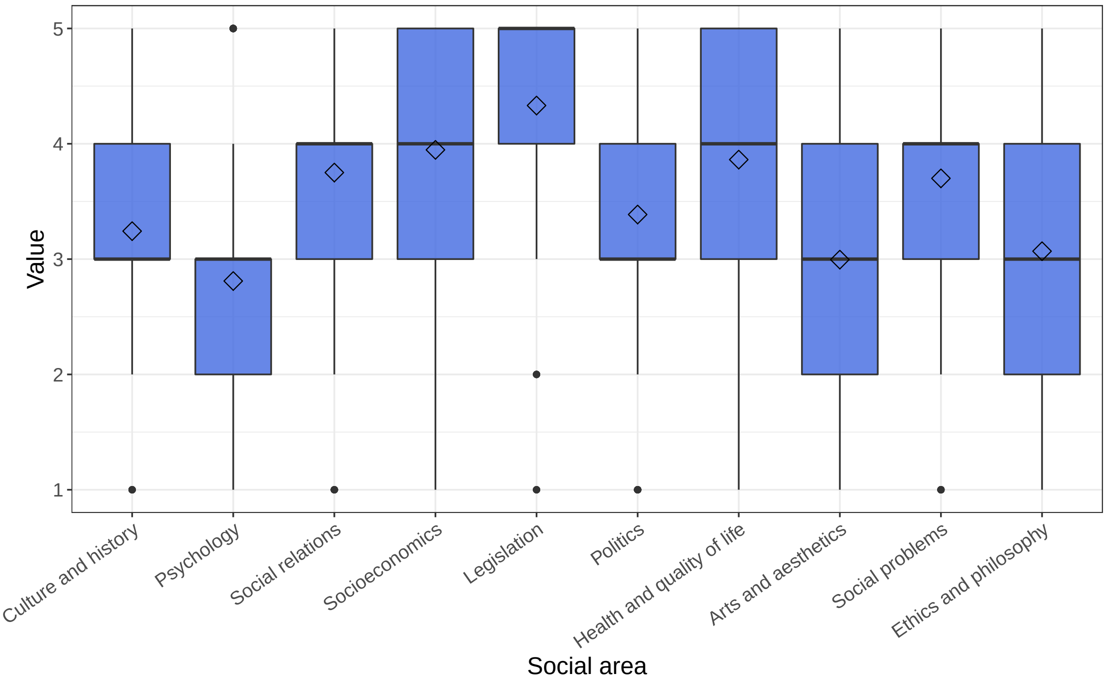

Figure 6.27. Boxplots of the answers for each technical skill

and results were more spread than for female respondents. For Social problems, data showed slightly higher variance and average for female respondents than for male ones.

On the other hand, larger differences can be observed from the boxplots where data is disaggregated by current occupation (Figure 6.29). In particular, the responses by practitioners were lower for all the items. This may point to a gap between what is perceived in industry and what is perceived in academia, which will be examined in more detail in following subsections.

In addition to the descriptive analysis above, chi-square tests were used to test whether there were significant differences between groups of respondents. The sociodemographic variables that were examined were gender (female, male), position (new students, undergraduate students, master and doctoral students, professors and researchers, and industry workers), age, maximum level of studies, and activities in which they participate outside of university and work (cultural, physical, creative, personal development, service to community, training, learning, or no activities).

The results of these tests are shown in Table B.16. As it can be seen, the chi-square test of independence performed to examine the relation between gender and perception towards the importance of hard skills showed that there was no significant association between the two variables. By contrast, significant relationships were found between position and the perception towards every technical social competency. Additionally, some statistically significant associations were found in the rest of the variables; the potential underlying reasons of these findings will be discussed in the following section.

With regard to the chi-square tests results, significant differences between population subgroups were analysed through chi-square tests, and, if results were significant, Bonferroni-Holm post hoc analyses were performed. Even though no significant differences were found in the responses between gender groups, there are significant differences in other population subgroups. First of all, there exist major differences between groups classified by current occupation (students, professors, and practitioners). These differences manifest themselves in the ten competencies that were analysed, with high significance in all the cases ($p < .001$). The post hoc comparisons revealed that perception towards each of

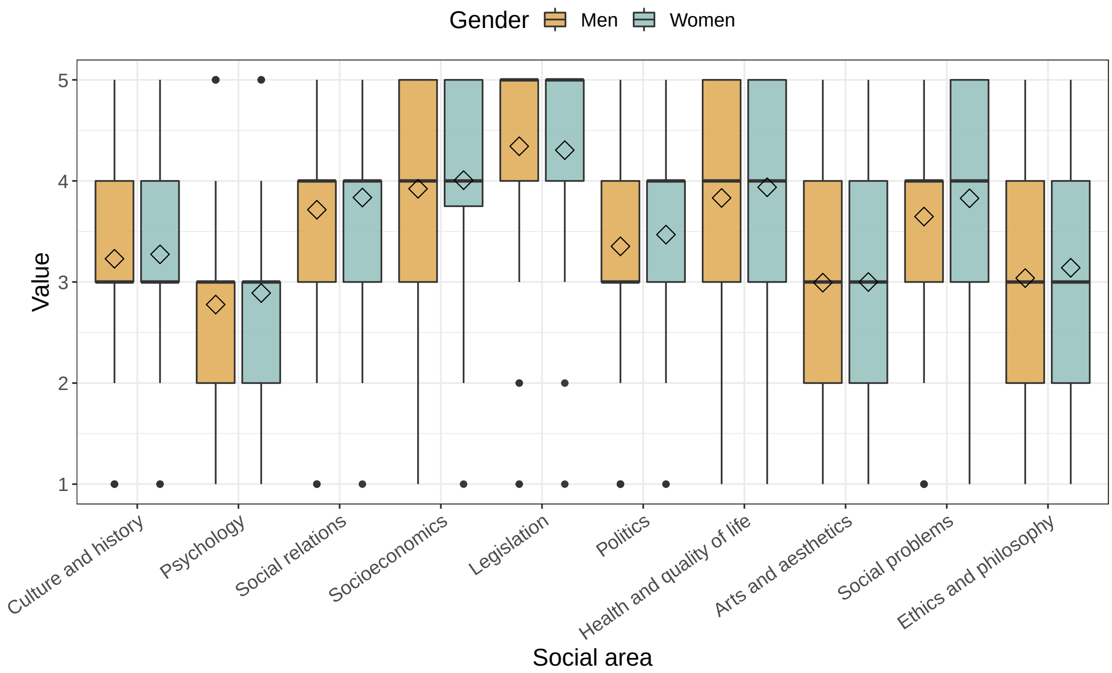

Figure 6.28. Boxplots of the answers for each technical skill, disaggregated by gender

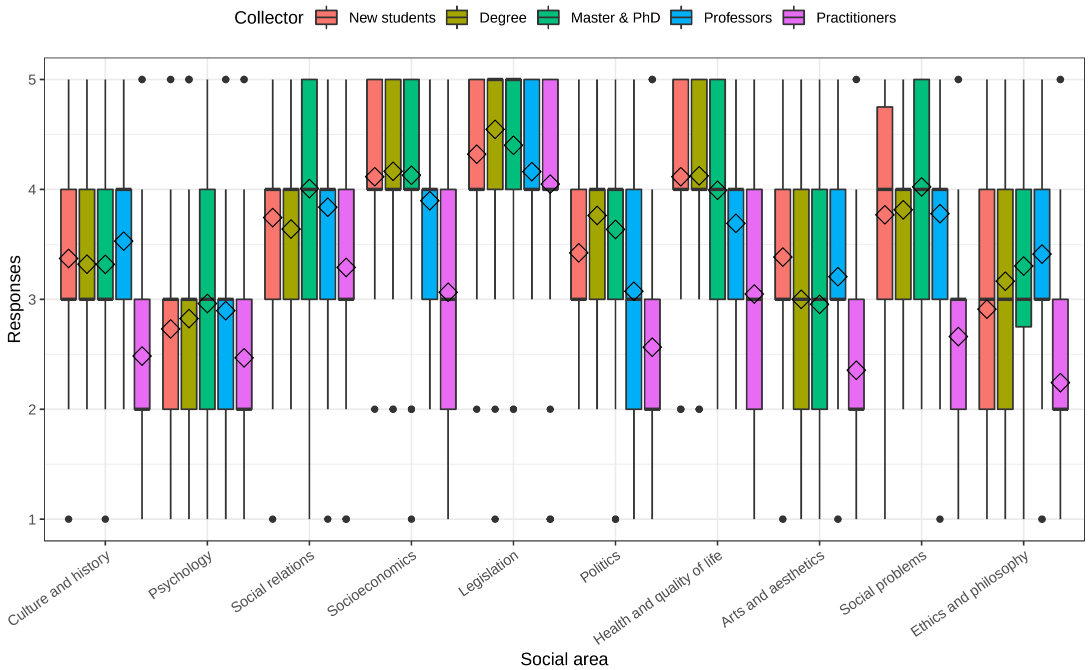

Figure 6.29. Boxplots of the answers for each technical skill, disaggregated by current occupation

the competencies was statistically different between practitioners and the remaining groups in all cases. The issue of the dichotomy of perceptions between practitioners and academia has been analysed by other authors, who have frequently advocated for closer connections between industry and academia (Enshassi and Hassouna (2005), García-Aracil and Van Der Velden (2008), Oyebisi et al. (1996)).

Significant differences for the subgroups "age" and "maximum level of studies" were also found. Even though there may be relationships between age, maximum level of studies attained, and current occupation of each individual, the results of the chi-square tests obtained were different for these variables. On the one hand, there were significant differences for different age groups regarding Socioeconomics, Legislation, Politics, Health and quality of life and Social problems. The post hoc comparisons in this case revealed that the statistical differences mainly arose from pairwise comparisons between the youngest respondents (less than 25 years old) and respondents above the age of 35. On the other hand, the chi-square tests showed that the items Culture and history, Social communications and relations, Socioeconomics, Politics, Health and quality of life, Arts and aesthetics, Social problems, and Ethics and philosophy were significantly associated to the maximum level of studies attained by the respondent.

Apart from gender, current occupation, age, and maximum level of studies, it is also interesting to discuss the significant differences found related to responses given to the leisure time activities. While no significant differences were observed for responses related to participation in sports, learning and service to community activities, differences were found when examining cultural, creative, spiritual development, training and learning activities. The following points summarise these results:

- In the association between perceptions towards Psychology and participation in cultural activities, chi-square test of independence revealed that people participating in cultural activities were more likely to perceive Psychology as more necessary.
- When examining the association between participation in cultural activities and perceived need of Legislation, the chi-square tests of independence revealed that individuals participating in such activities were more likely to perceive a medium need for Legislation.
- The chi-square test examining the relationship between Arts and aesthetics and participation in cultural, and creative activities showed significant differences.
- The association between Social problems and participation in cultural, and spiritual development activities showed significant differences in the chi-square tests of independence.
- Finally, Ethics and philosophy was found to be significantly associated with the responses given by individuals participating in cultural, and spiritual development activities.

6.4.1.3. Factor analysis

Factor analysis was used to find underlying factors of the responses. Both the results of the eigenvalues and parallel analyses demonstrated the need for considering three factors in the analysis. Factor analysis was performed using polychoric correlation matrices and principal axis method for factor extraction (Van Der Eijk and Rose, 2015), which has been recommended in cases in which variables are highly discrete ordinal, as happens with the Likert scale. The first three factors accounted for 45.1% of the total variance. Table 6.13 shows the weights of each of the three factors found.

The results of the factor analysis showed that, regarding the frequency in which they are perceived to be needed in practice, these skills can be classified into three groups. The first factor comprised the areas Social problems, Health and quality of life, Culture and history, Ethics and philosophy, and Arts and aesthetics; the second factor included the areas Legislation, Socioeconomics, and Politics; finally, the third factor comprised Social communications and relations and Psychology. As it can be seen, the first factor comprised some social areas that are more strongly related to the individual, while the third factor integrated elements more related to relationships between individuals. As for the second factor, it contains elements that are generally labelled as business areas.

In addition to the above, Figures 6.30 and 6.31 show biplots of the results coloured by gender and by current occupation, respectively. As for gender, no major differences can be observed for the 95% interval of the scores of male and female respondents. On the contrary, regarding current occupation, as it can be seen, the 95% interval of the scores of students and professors is similar, whereas there is

Table 6.13. Loadings of the three factors for each technical skill

	Factor loadings			Communality
	1	2	3	
Culture and history	**0.613**		0.151	0.483
Health and quality of life	**0.636**	0.201	-0.188	0.432
Arts and aesthetics	**0.586**			0.301
Social problems	**0.690**			0.572
Ethics and philosophy	**0.595**	-0.125	0.233	0.502
Socioeconomics		**0.597**	0.263	0.595
Legislation		**0.772**		0.554
Politics	0.230	**0.550**		0.488
Psychology	0.17		**0.648**	0.546
Social communications and relations		0.172	**0.700**	0.564
Proportion Var	20.5	13.5	11.0	

a greater difference with the 95% confidence interval of the scores of practitioners. In fact, it needs to be noted that the structure of the factors differed slightly for the different population subgroups, showing that the latent variables influencing the perceived need for each area is different.

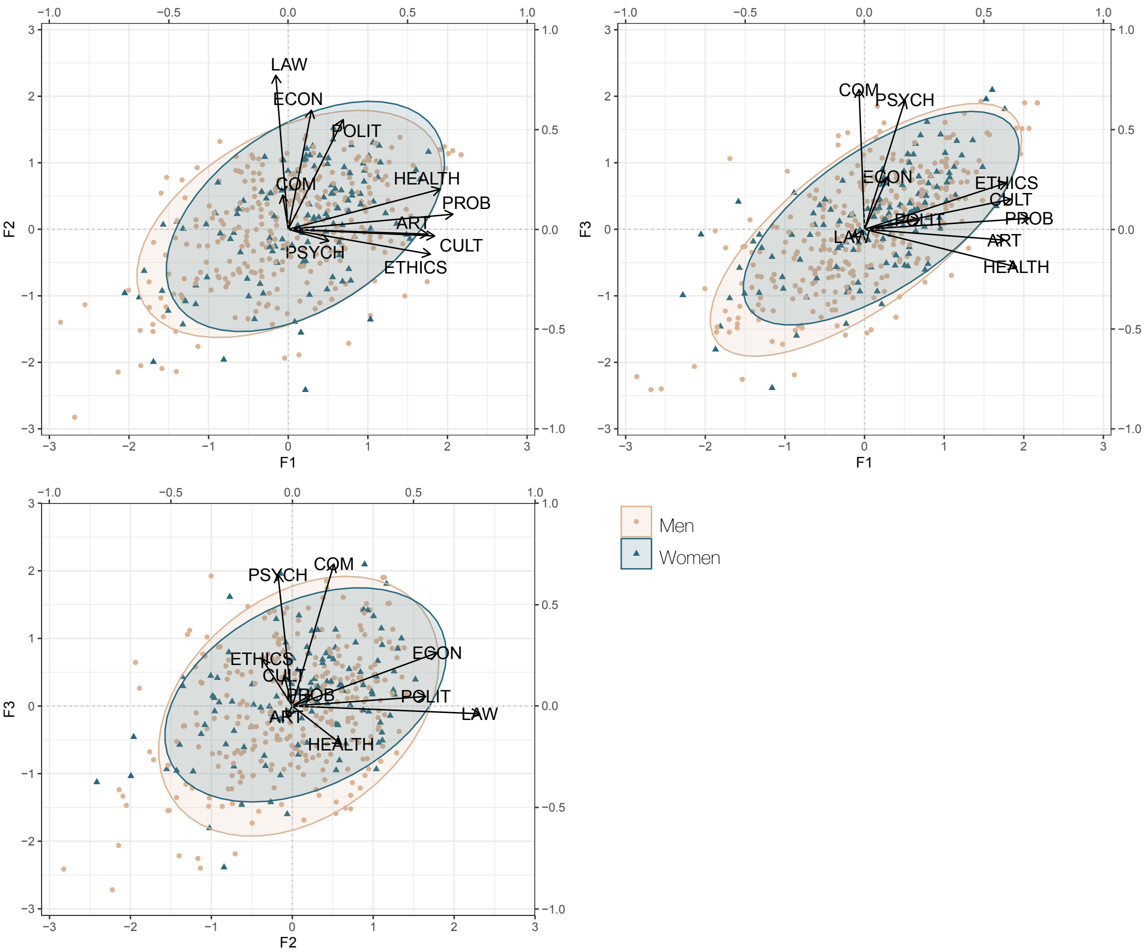

Figure 6.30. Biplots of the factor loadings for technical skills, coloured by gender

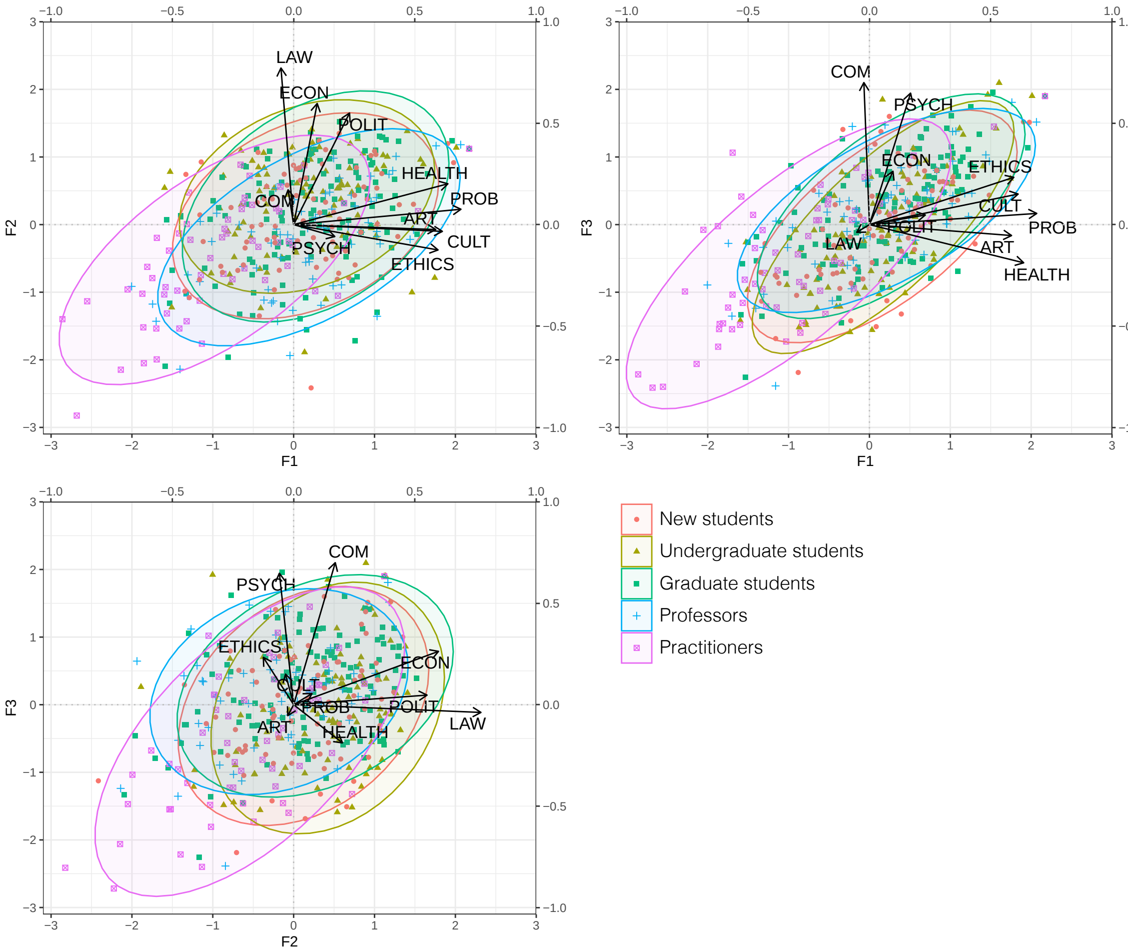

Figure 6.31. Biplots of the factor loadings for technical skills, coloured by current position

6.4.2. Transversal skills

The results of the question on technical social competencies are shown in Figure 6.32. The competencies that had higher ratings in the responses were Teamwork ($\mu = 4.69$), Communication skills ($\mu = 4.53$), and Flexibility and adaptability ($\mu = 4.38$), whereas the ones with lower ratings were Maths and physics ($\mu = 4.03$), Creativity and innovation ($\mu = 4.14$), and Interpersonal skills ($\mu = 4.24$).

A first aspect to highlight from these results is that, even though civil engineering programs, explicitly or implicitly, are mostly based on mathematical and physics courses, it is a skill that is less frequently used in practice, according to the perceptions by practitioners (see 6.33 for the results by gender and 6.34 for the results by respondent group). In fact, it is interesting to note how this perception decreases with age. The mean of the responses by new students is 4.47, whereas the responses by practitioners have a mean of 3.34. This item represents, in fact, the skill with the lowest mean value for practitioners in comparison to the other 10 items.

6.4.2.1. Associations between variables

The same sociodemographic variables as in the previous sections were used in the chi-square tests to test whether there were significant differences between groups of respondents. The corresponding results have been included in Table B.20. As it can be seen, compared to the previous tests, less significant associations were found within the different groups.

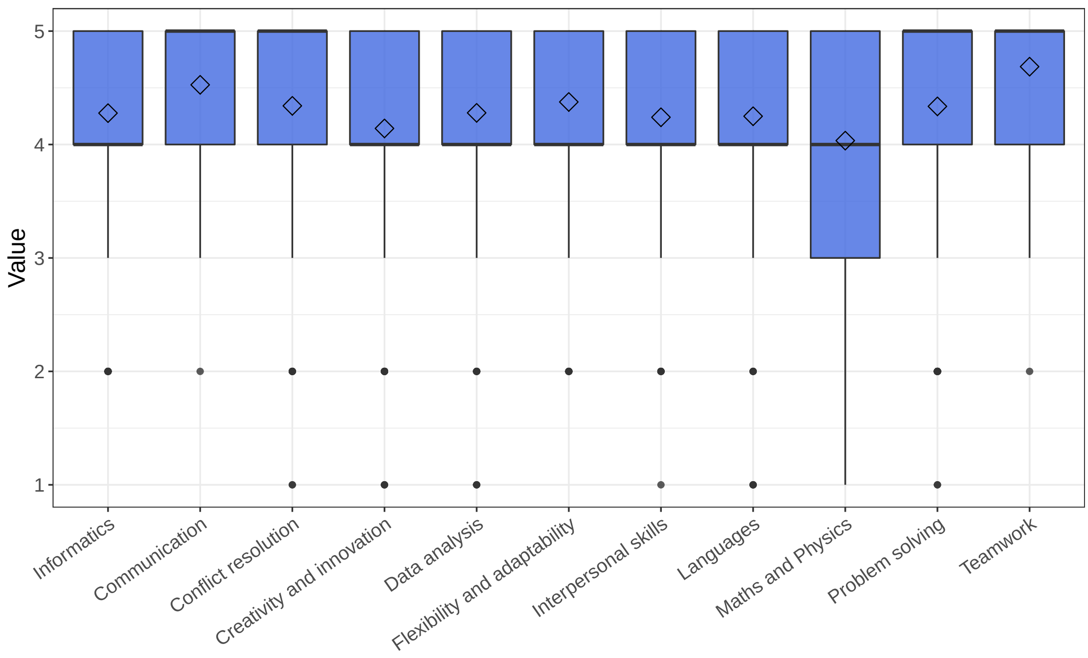

Figure 6.32. Boxplots of the answers for each transversal skill

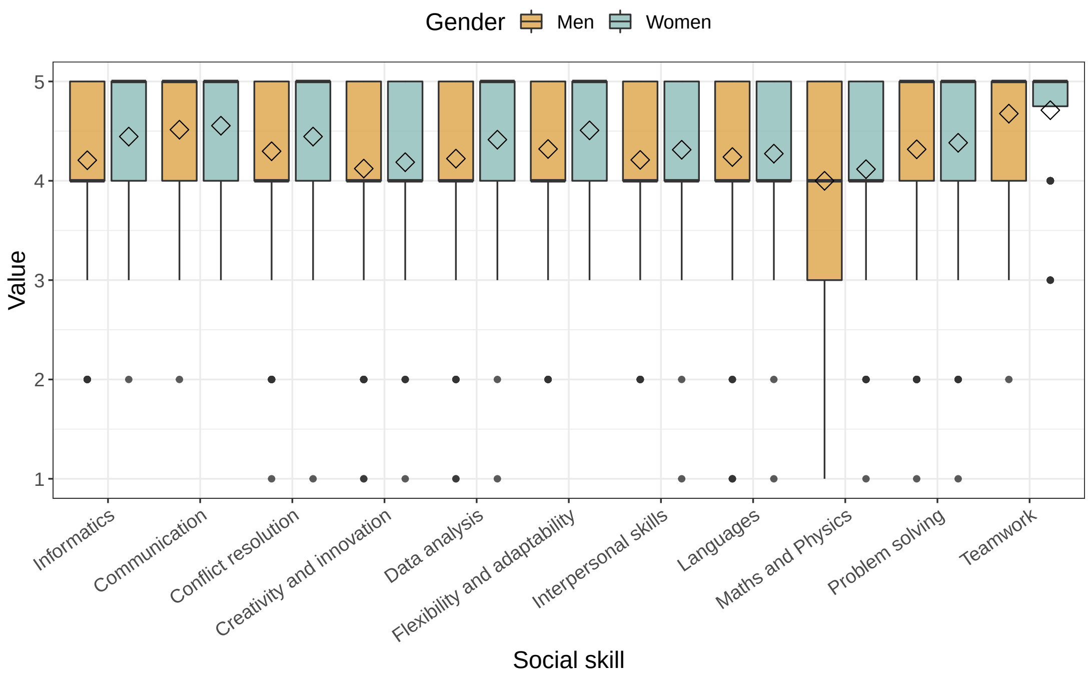

Figure 6.33. Boxplots of the answers for each transversal skill, disaggregated by gender

Compared to responses for technical competencies, less significant differences were found for the different subpopulations regarding transversal competencies. Regarding gender, only differences were found for Informatics. For the case in which respondents were grouped by current occupation, significant differences were found in items Conflict resolution, Creativity and innovation, Data analysis, Languages, Maths and physics, and Problem solving. Post hoc comparisons for the item Conflict resolution, Creativity and innovation, and Problem solving showed that practitioners were more likely than

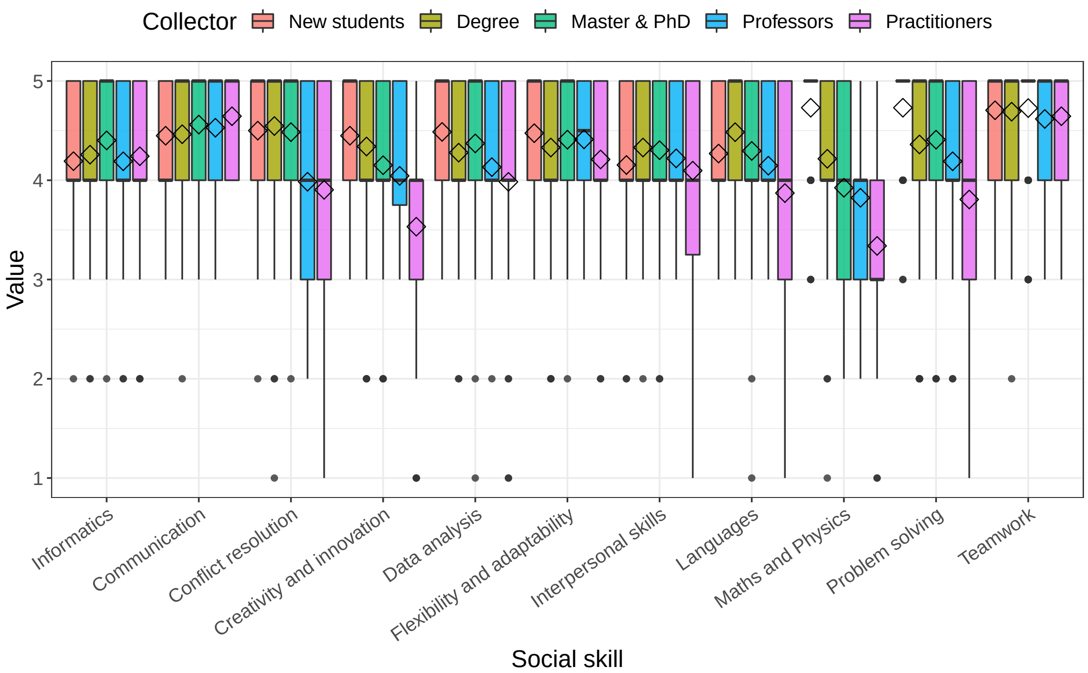

Figure 6.34. Boxplots of the answers for each transversal skill, disaggregated by current occupation

new, undergraduate, and graduate students to perceive these competencies as less necessary. As for Maths and physics, the post hoc comparisons revealed that practitioners are more likely to consider Maths and physics less necessary than the other groups, including students, as well as professors. Regarding Data analysis, the chi-square test and corresponding post hoc comparison showed that practitioners were more likely to consider Data analysis less necessary than new students, who considered it more necessary. Similarly, Languages yielded the same results, but for the difference between practitioners and both new students and undergraduate students.

As for the association between the different items and participation in certain activities, only Communication skills and Interpersonal skills showed significant differences. In particular, the chi-square test examining the relationship between Communication skills and participation in spiritual development activities showed significant differences. Besides, the association between Interpersonal skills and not participating in any activity showed as well showed significant differences in the chi-square tests of independence.

6.4.2.2. Latent variable analysis

As it was done before, factor analysis was carried out to find the latent variables of the perceptions towards transversal skills. The eigenvalues and parallel analysis all demonstrated the need for considering three factors in the analysis. The first three factors accounted for 43.1% of the total variance. Table 6.14 shows the weights of each of the three factors for each competency asked for in the questionnaire.

The analysis of the factors of the items revealed that the competencies could be structured in three different factors. In particular, the first factor comprised the areas Teamwork, Languages, Interpersonal skills, Flexibility and adaptability, Creativity and innovation, and Conflict resolution; the second factor included the areas Problem solving, and Maths and physics; finally, the third factor comprised Informatics and Communication skills. Items Communication skills and Data analysis had similar loadings in more than one factor. Communication skills factored highly in factor 1 and factor 2. Data analysis had the highest factor in factor 2, followed by the third factor.

Table 6.14. Loadings of the three factors for each transversal skill

	Factor loadings			
	1	**2**	**3**	**Communality**
Interpersonal skills	**0.722**			0.518
Languages	**0.689**		-0.137	0.448
Teamwork	**0.549**		0.136	0.431
Conflict resolution	**0.539**	0.285		0.493
Creativity and innovation	**0.520**	0.275		0.430
Flexibility and adaptability	**0.500**	0.102	0.211	0.450
Communication (written and verbal)	**0.478**	-0.222	0.468	0.579
Maths and physics		**0.718**		0.495
Problem solving	0.188	**0.678**		0.614
Data analysis	0.183	**0.403**	0.274	0.410
Informatics		0.129	**0.748**	0.567
Proportion Var	21.9	12.6	8.6	

Additionally, Figures 6.35 and 6.36 show the biplots for the results of the factor analysis, coloured by gender and current occupation respectively.

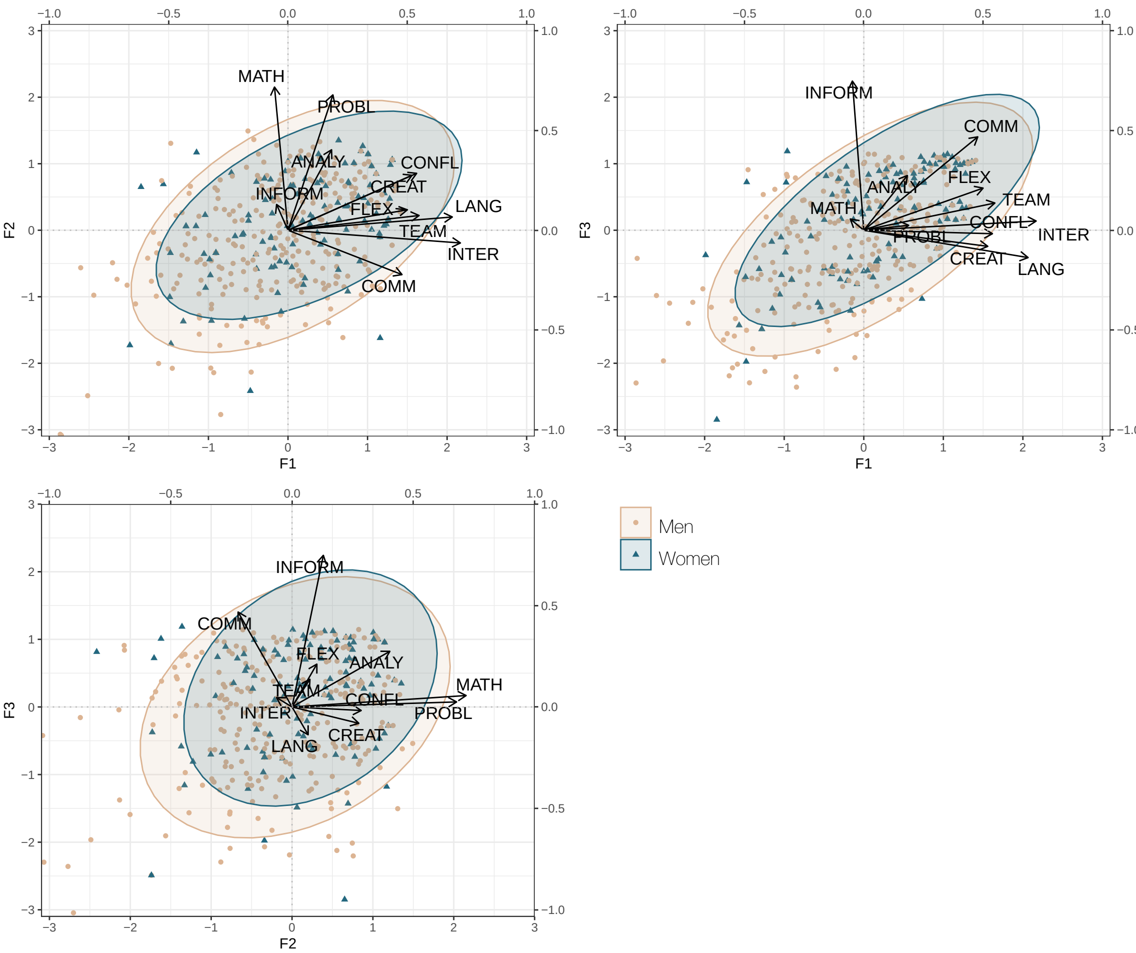

Figure 6.35. Biplots of the factor loadings for transversal skills, coloured by gender

As it happened before, the 95% confidence interval of the scores of students and professors is more

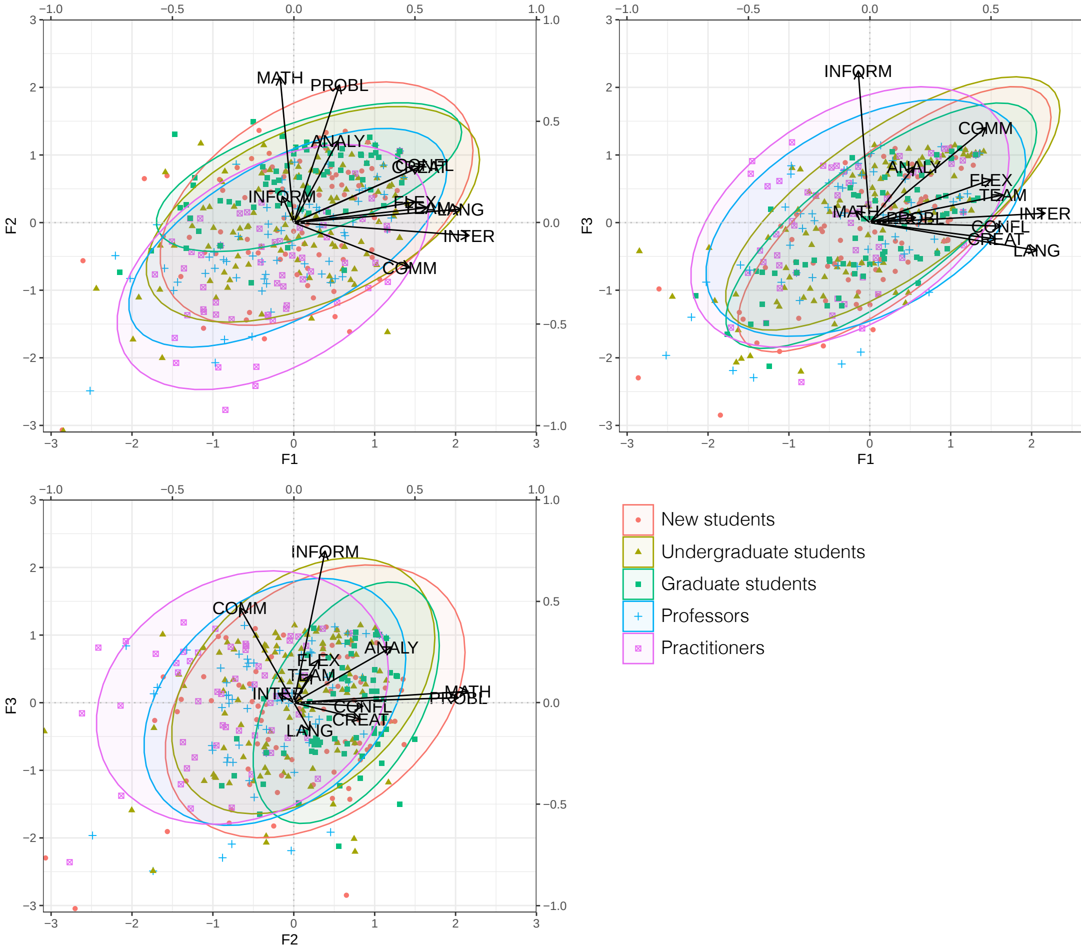

Figure 6.36. Biplots of the factor loadings for transversal skills, coloured by current occupation

aligned than the 95% confidence interval of the scores of practitioners, which does not match as well with the others. However, contrary to what occurred with technical competencies, the factor structure did not show many differences for the different population subgroups.

6.5. Summary

This chapter served the purpose of analysing three issues that arose from the literature review and interviews by comparing the perspectives of professors, students and practitioners.

In particular, the first part of the chapter analysed how the "social" dimension is conceptualised, and how its relative importance is perceived. Results showed the contribution that civil engineering has on society is perceived as a medium level one, where the highest contributions were allocated from medicine and the lowest ones from artistic disciplines. Besides, the results of the latent variable analysis showed that the perception of this contribution of civil engineering is explained by the same factors as those explaining the responses given to natural and physical sciences.

Within the discipline of civil engineering, all subdisciplines were considered to have high social contributions, albeit water engineering stood out as the one perceived to have the largest impact on society. Even though the results of the Mokken scaling did not show any potential latent variable, factor analysis indicated that the subdisciplines could be grouped into three divisions according to the factor explaining the responses given to the question. In addition to this, significant differences were found for these factors when comparing responses from male and female participants, and when comparing responses from new students to the other respondents.

The second part of the chapter examined in more detail the content from the social sciences and humanities that is perceived as necessary among students, which was later compared to the perceptions from professors and practitioners. It was seen that the perceptions by new students of what social sciences and humanities they should be taught matches well with what current students think they have been taught.

The final part of this chapter focused on social competencies, and how the need for certain technical and transversal competencies are perceived differently by students, professors and practitioners. It was seen that both students and professors have a tendency to have perceptions towards social competencies that are different from those working in the industry. These differences are more significant for technical social competencies than for transversal competencies.

7

Practical implications

This chapter is partially based on the following articles:

Josa, I., de la Fuente, A., Casanovas-Rubio, M.M., Armengou, J. & Aguado, A. (2021). Sustainability-Oriented Model to Decide on Concrete Pipeline Reinforcement. *Sustainability*, 13(3026). DOI: 10.3390/su13063026.

Josa, I., Pons, O., de la Fuente, A. & Aguado, A. (2020). Multi-criteria decision-making model to assess the sustainability of girders and trusses: case study for roofs of sports halls. *Journal of Cleaner Production*, 249. DOI: 10.1016/j.jclepro.2019.119312.

The doctoral candidate contributed 90% of the work presented here.

7.1. Introduction

In the previous chapters of this dissertation, the different conditions affecting in some way the introduction of various social dimensions in civil engineering programmes were analysed. Results of interview data showed that there are four principal factors that influence the process of integrating SSH in CE degrees. Multiple stakeholders have a role in these factors and, in general, in the various processes shaping higher education institutions (Marshall, 2018).

According to Amaral and Magalhães (2002), stakeholders in higher education can be classified as internal or external. On the one hand, according to the authors, internal stakeholders are those members of the higher education community that "participate in the daily life of the institutions". This comprises students, faculty staff, non-academic personnel, and management and governance team members. On the other hand, external stakeholders refer to the "groups or individuals that have an interest in higher education" but that do not participate in its regular activities. This consists of governmental agencies, employers, society in general, and any relevant collective within society, such as students' parents or professional associations.

The classification made by Amaral and Magalhães (2002) is not the only one that has been proposed to characterise stakeholders in higher education. Kettunen (2015) described the most relevant stakeholders through a stakeholder map and also characterised the relationships between various higher education actors. In the map he developed, he considered four different perspectives that stakeholders could take: external, finance, processes and structures, and organisational learning.

All the stakeholders described above could have an important role when it comes to making changes at different levels of the different university functions. Nevertheless, internal stakeholders of higher education have been regarded as important agents of change (Stephens et al., 2008). And, in particular, among these stakeholders, professors are essential in the process of student transformation. They have a critical role in teaching the curriculum and are therefore responsible for furthering university graduates' skills development. Hence, giving them tools may be a highly impacting strategy.

Concerning the role that professors can have in the learning processes of students, there are two elements identified in the previous chapters that can be key to advance towards the integration of SSH in CE programmes that is being discussed in this thesis. On the one hand, results showed that the emerging sustainability discourse is making an impact towards understanding how the social may fit within specific civil engineering courses or degrees. On the other hand, many interviewees mentioned the fact that some civil engineering disciplines are usually seen as more favourable for integrating societal issues. On the contrary, courses such as structural analysis or material science were also highlighted as areas of study in which relevant content from the SSH is not easily incorporated. Note that there were a few cases reported by the interviewees that proved that this does not always hold.

Having said this, in this chapter, the two issues described above, sustainability as a driver and the misleading conception that it is not possible to incorporate SSH in certain subjects, are combined to provide specific approaches which may help educators to introduce the SSH in their courses. For this, the use of multi-criteria decision-making (MCDM) tools is proposed as the base for the development of two case studies.

MCDM methods have arisen in the last decades as key to address the complexity inherent to introducing indicators from different areas, in different units and with different relative importance in the decision-making processes. In the context of sustainability, these tools are fundamental, as they can consider a multiplicity of factors such as economic, environmental and social aspects. In the context of education, they provide an opportunity to integrate knowledge from different courses into a single case study, and to support the development of specific competencies that may be required by the school.

In particular, two important competencies in advanced civil engineering courses are the following[1]:

- Knowledge of all types of structures and their materials, and ability to design, design, execute and maintain civil works structures and buildings.
- Knowledge and ability for structural analysis through the application of methods and programs of design and advanced calculation of structures, from the knowledge and understanding of the applications and their application to the structural typologies of civil engineering. Ability to perform structural integrity assessments.

Besides from the above, it is common practice for higher education institutions to define a set of transversal competencies that are assigned to different courses when the degree is created. In the case of the Technical University of Catalonia, these competencies include the following:

- Entrepreneurship and innovation
- Sustainability and social commitment
- Effective oral and written communication
- Teamwork
- Solvent use of information resources
- Autonomous learning
- Third language

[1]These competencies have been extracted from the civil engineering curriculum in the Technical University of Catalonia, but similar skills may be defined in other schools.

- Gender perspective

Throughout the development of the study cases that are presented in this chapter, the way in which the above competencies may be developed will be described.

Having said this, and in order to set the background of the method that will be used for the case study, the following section briefly reviews the literature of MCDM methods, as well as the tool used for the case studies. Then, the two different applications are described, including what contents they allow to deal with in class. The last section concludes.

7.2. Multi-criteria decision-making methods

Making decisions is inextricably linked to many areas of our lives This explains why multi-criteria decision-making (MCDM) methods have arisen as key to address the complexity inherent to introducing indicators from different areas, in different units and with different relative importance in the decision-making processes. In the context of sustainability, these tools are fundamental, as they can consider a multiplicity of factors such as economic, environmental and social aspects.

There exist many different MCDM methods, including Analytic Hierarchy Process (AHP, Saaty, 1986), Simple Additive Weighting (SAW, Tzeng and Huang, 2011), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS, Yoon, 1987), Multicriteria Optimization and Compromise Solution (VIKOR, from Serbian *VIseKriterijumska Optimizacija I Kompromisno Resenje*, Duckstein and Opricovic, 1980, Opricovic and Tzeng, 2004, 2007), Elimination and Choice Translating Reality (ELECTRE, from French *ELimination Et Choix Traduisant la REalité*, Benayoun and Sussman, 1966, Benayoun et al., 1966), Preference Ranking Organization METhod for Enrichment Evaluation (PROMETHEE, Brans et al., 1986), Characteristic Object Method (COMET, Kizielewicz and Kolodziejczyk, 2020, Kizielewicz and Sałabun, 2020, Sałabun, 2014), and MIVES. Most of these methods have been used to date in the field of civil engineering. The reader can find a review of specific ways and contexts in which they have been utilised in civil engineering in Jato-Espino et al., 2014, Nadkarni and Puthuvayi, 2020, Navarro et al., 2019.

In general terms, the differences between each method arise from the ways in which the different steps involved in the decision-making process are carried out. In particular, the main steps are the selection of indicators, the normalisation of the indicators, the weighting technique, the aggregation of indicators, the sensitivity analysis, and obtaining the final ranking of alternatives. In fact, several authors have highlighted the fact that the choice of the method can have a significant influence on the final results (Sałabun et al., 2020, Shekhovtsov and Kolodziejczyk, 2020).

According to several authors (see, for instance, Kizielewicz and Sałabun, 2020), the different existing methods can be grouped into three different trends according to their characteristics. These groups are the American school, which includes methods that are based on usability or value, and which exclude incomparability of different alternatives; the European school, which generally uses relationships of indifference, incomparability between options, and both weak or strong preferences; and the rule methods, which lie between the two schools.

Some of the above-mentioned methods suffer from some drawbacks, such as the fact that they are time-consuming and lack intuitiveness (Kabir et al., 2014), which goes against the aim of developing a method that is suitable for policy-makers. Another flaw is the fact that the criteria values used can only be positive and maximising (Velasquez and Hester, 2013), which makes calculations more complex if minimising indicators are to be used. A thorough review of advantages of disadvantages of each method is out of the scope of the present chapter, but some comparisons between different methods can be found in Karni et al. (1990), Sałabun et al. (2020), Shekhovtsov and Salabun (2020), Triantaphyllou

(2000).

At this point, it needs to be noted that various MCDM methodologies could have been used in the present study. However, there were several characteristics that led the authors to choose one in particular. The present analysis required a method that allowed flexibility and adaptability to the specific requirements of the decision, as well as transparency concerning how the data is processed. This is particularly important for cases in which the decision may involve the opinion of third-parties, and it needs to be presented to non-expert stakeholders. These are the reasons why the rule-based method MIVES was considered to be the most suitable tool, due to its simplicity but also rigour.

Besides, MIVES has previously been used and accepted by other researchers and technical committees for this type of analysis in several fields, such as: underground (Alberti et al., 2018a) and hydraulic (Pardo-Bosch and Aguado, 2015) infrastructures; buildings (Pons and De, 2013, Pons et al., 2016); industrial construction (San-José Lombera and Garrucho Aprea, 2010); urban development (Pujadas et al., 2017); electricity generation infrastructure (Cartelle Barros et al., 2015) and, even, post-disaster housing management (Hosseini et al., 2016).

7.2.1. MIVES

The Integrated Value Model for Sustainability Evaluations (MIVES, from the Spanish *Modelo integrado de valor para evaluaciones sostenibles*) is a methodology for taking multi-criteria decisions. With it, each alternative of a given problem is evaluated using an index.

The method is carried out in various phases, which are the following ones:

1. **Delimitation of the decision**: the decision maker is defined, and the system limits and boundary conditions are set.
2. **Introduction of the decision-making tree**: the aspects that will be taken into account in the decision are structured in the form of a tree.
3. **Creation of value functions**: some functions are created to be able to obtain evaluations of 0 to 1 of all the aspects belonging to the last branch of the decision-making tree.
4. **Assignment of weights**: the relative importance of each of the aspects is assigned in relation to the rest belonging to the same branch of the decision-making tree.
5. **Definition of the alternatives**: various feasible alternatives to the problem of taking decision raised. In some cases, the alternatives are pre-set at the beginning of the decision making. decision and therefore, this phase should not be carried out.
6. **Evaluation of the alternatives**: the value index is obtained for each of the alternatives raised.
7. **Sensitivity analysis**: the possible change in the value index of each one of the alternatives in the case of varying the weights or the value functions defined in the early stages. This phase is optional within the MIVES methodology.
8. **Contrast of results**: it is checked, in the long term, if the valuation model continues to adjust to what you wanted to value initially and if the calculations made in each of the alternatives is as expected. This phase can be considered as a phase of control, of the model and of the alternatives, and it is also optional within the MIVES methodology.

7.2.1.1. Decision-making tree

The decision-making tree is the structuring in the form of a tree of all those aspects that will be studied. There are several levels in the decision-making tree branch, while each branch can be subdivided into many or a few sublevels. At the first level are the requirements that are the main aspects that make up the decision. At the intermediate levels are the criteria and sub-criteria, and at the last level of the branch appear the most specific aspects that are going to be directly evaluated: the indicators. Which is not the case with the criteria and requirements.

7.2.1.2. Value functions

The main objective of the value function is to be able to compare the values of the indicators with different measurement units. This way, a weighted sum of the different values of each of the indicators can be obtained. The value function allows going from the quantified value of a variable or attribute to a dimensionless variable that ranges between 0 and 1. The value function used is defined by five parameters that allow obtaining various kinds of shapes. These shapes are S-shaped, concave, convex, or linear ones.

The parameters that define the type of function are: K_i, C_i, X_{max}, X_{min} and P_i (equation 7.1 for increasing functions). The value of B is calculated based on the 5 previous values (equation 7.2).

$$V_{ind} = B \cdot \left[1 - e^{\left(-K_i \cdot \left(\frac{|X_i - X_{min}|}{C_i}\right)^{P_i}\right)}\right] \tag{7.1}$$

where:

X_{min} is the value in abscissa, whose value is equal to zero (in the case of increasing value functions).
X is the abscissa of the evaluated indicator (variable for each alternative).
P_i is a shape factor that defines whether the curve is concave, convex, linear, or S-shaped. Obtaining concave curves for values of $P_i < 1$, convex or in the form of “S” if $P_i > 11$ and tending to linear for values $P_i = 1$. It also roughly determines the slope of the curve at the point of coordinate inflection $(C_i,\ K_i)$.
C_i approaches the abscissa of the inflection point.
K_i approaches the ordinate of the inflection point.
B is the factor that allows the function to remain in the value range from 0 to 1. This factor is defined by equation 7.2.

$$B = \left[1 - e^{\left(-K_i \cdot \left(\frac{|X_{max} - X_{min}|}{C_i}\right)^{P_i}\right)}\right]^{-1} \tag{7.2}$$

Alternatively, decreasing functions can be used, that is, they adopt the maximum value in X_{min}. The only difference of the value function is that the variable X_{min} is replaced by the variable X_{max} without more than expressing the value of the function (V_{ind}) and that of the parameter ”B” from the expressions in equations 7.3 and 7.4.

$$V_{ind} = B \cdot \left[1 - e^{\left(-K_i \cdot \left(\frac{|X_i - X_{max}|}{C_i}\right)^{P_i}\right)}\right] \tag{7.3}$$

$$B = \left[1 - e^{\left(-K_i \cdot \left(\frac{|X_{max} - X_{min}|}{C_i}\right)^{P_i}\right)}\right]^{-1} \tag{7.4}$$

The equation of the value function varies according to the values assigned to the constants: KK_i, C_i, X_{max}, X_{min} and P_i.

7.2.1.3. Sensitivity analysis

In MIVES, sensitivity analyses are carried out to determine the influence of different parameters of the model on the index and the value obtained for each alternative.

One way to perform this sensitivity analysis is by using a Monte Carlo analysis. The Monte Carlo method is a non-deterministic (or probabilistic) method, used to approximate complex mathematical expressions that are difficult to evaluate accurately. The Monte Carlo method provides approximate solutions to a great variety of mathematical problems, making it possible to carry out experiments with samples of pseudo-random numbers. The method is applicable to any type of problem, be it stochastic or deterministic.

In practice, to apply Monte Carlo in MIVES it is first necessary to choose the variables that may have a probabilistic behaviour. Probabilistic variables can include indicators, weights and parameters of the value functions. It is recommended that only those variables with the greatest influence on the model and a high degree of uncertainty are established as probabilistic, particularly in models that include a large number of variables.

Then, the values of the model are estimated in both the deterministic and the probabilistic cases. In addition to expert advice, historical databases can be helpful here. For probabilistic variables, it will be necessary to define what type of probability function is appropriate and, based on this choice, its parameters must be defined (unfortunately, in this context, there are no databases that cover the minimum, maximum, mode...).

For continuous numerical variables, two commonly used distributions are the triangular distribution and the beta pert. They are easy to handle as they only involve estimating extreme and modal values. They are also easy to understand. Also, these distributions can be configured to be asymmetric.

7.3. Integration of the "social" in a structures course

The first application of a MCDM model as a class activity lies in the context of structures. The following sections describe the context in which the study is located, as well as the model developed and the discussion of the results.

7.3.1. Context

Within the large body of literature dealing with multi-attribute models that allow evaluating sustainability, authors have generally used multi-criteria models to assess sustainability in the construction sector to either analyse buildings from a holistic perspective or other types of infrastructures different from buildings. However, it is necessary to dispose of sustainability assessment approaches that enable to determine the extent to which different parts of the infrastructure contribute to its overall sustainability. Additionally, most analyses comparing materials in terms of sustainability have focused on their environmental impacts, hence, this approach can compromise economic and social aspects (Meysam et al., 2018).

In this regard, no proposals have been made that could support decision-makers in both an appropriate material and the suitable structural typology for a specific building's component was found into the scientific literature.

Besides from the above, in structural analysis courses, problems tend to be bounded to a greater or lesser extent. Hence, students are frequently asked to design structural elements of specific characteristics (regarding length, material, boundary conditions...). Therefore, the gap in the literature described previously, together with the need for proposing didactic activities to students in structural analysis courses in which they need to think of social issues apart from the purely functional ones set the base for the present study case.

In view of the abovementioned, the development of this first case has two main objectives:

- To propose a MIVES-based model to assess the sustainability of structural components.
- To use this model to deal with the sustainability evaluation of the most representative alternatives (materials and structural typologies) for girders and trusts for the construction of sports halls' roofs in Spain.
  These facilities are structurally representative and versatile of other uses as one-storey-framed buildings (e.g., industrial purposes, markets or shopping centres). Likewise, the girders that are used for this application are also meant to fulfil several architectural, aesthetics and other social requirements which are rarely evaluated and, if so, this is done in a rather subjective manner.

7.3.2. Analysis model

In this section, a possible model aimed at assessing the sustainability of the different alternatives for the roof's structural elements is proposed based MIVES. For this, three requirements were established: economic, environmental and social, these being the three reference pillars onto which sustainability is supported according to United Nations (2005).

The definition of the criteria and indicators for each of the three requirements is of great importance for both the representativeness and reliability of the results. Therefore, students can be advised to ensure the adequacy of the assessment model by carrying out seminars with experts, as well as by searching academic and technical study case publications in the same field (e.g., Akadiri et al., 2013, Mahmoudkelaye et al., 2019, Meysam et al., 2018).

Figure 7.1 shows the decision-making tree with its three corresponding levels as well as with the weights assigned to each of the aspects. As for the weights, these were assigned based on guidelines given in publications made in the same field (Fib, 2017) and confirmed according to experts' criteria as it was mentioned above. The units of measurement of the defined indicators can be found in Table 7.1.

Table 7.1. Values of the parameters of each of the indicators' value functions

Indicator		Units	Function	X_{min}	X_{max}	C	K	P
I_1	Direct costs	€	DS	10000	0	7000	2.5	4
I_2	Maintenance/reparation costs	€	DS	25	0	17	2.5	4
I_3	CO_2 emissions	$kgCO_2$	DS	13000	0	6500	0.1	2.5
I_4	Energy	MJ	DS	130000	0	65000	0.1	2
I_5	Water	m^3	DS	9	0	4.5	0.1	2.5
I_6	Material	points	IL	2	9	1	0	1
I_7	User's comfort	points	IL	4	14	1	0	1
I_8	Context adaptability	points	IL	1	3	1	0	1
I_9	Construction time	points	DL	3	1	1	0	1
I_{10}	Installations	points	IL	1	3	1	0	1
I_{11}	Safety during construction	points	IL	1	3	1	0	1
I_{12}	Safety during service	points	IL	1	3	1	0	1

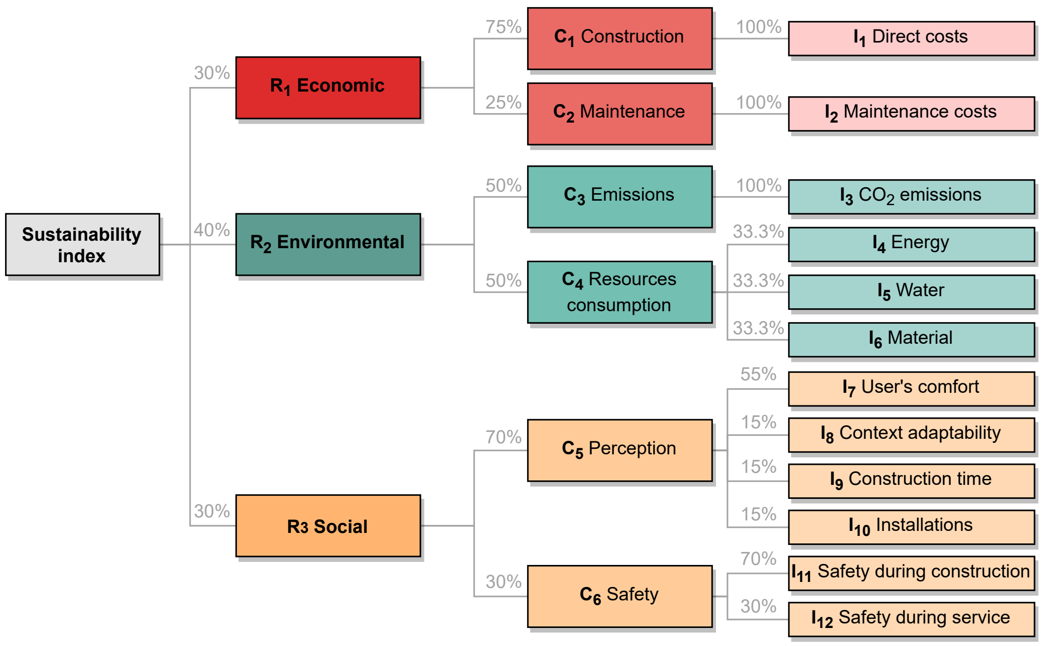

Figure 7.1. Decision-making tree model for the study case

7.3.2.1. Economic requirement

The economic requirement is represented by two criteria: *construction costs* (C_1) and *maintenance costs* C_2.

The first one, C_1, is made up of an indicator that includes the *direct costs* (I_1); namely, those costs attributable to the material, to the transportation and to the installation. These three items are added up in order to obtain the indicator's value. The evaluation of these costs has been carried out using two different methodologies. First of all, different costs databases and costs simulators were examined. For the material and installation costs, CYPE and ITEC databases were used. For the transportation costs, a costs simulator was used (OTEUS (Observatorio del Transporte de Euskadi)). These databases were chosen because they provide prices adjusted to the context in Barcelona, Spain, which is the area and the country in which the study cases have been located. Secondly, three discussion boards (for steel, concrete and timber respectively) were held in order to verify that the results obtained from the databases were appropriate.

The second criterion, *maintenance* (C_2), covers the costs related to the maintenance of the infrastructure. No reparations for accidental actions have been considered. On this point, the information that has been used is from the database elaborated by CYPE and from recommendations given in real projects. The two groups of data have been contrasted to check their coherence.

7.3.2.2. Environmental requirement

The environmental requirement is comprised of two criteria: *emissions* (C_3) and *consumption of resources* (C_4).

The objective of criterion C_3 is to favour those alternatives with a lower impact in terms of CO_2 emissions. Therefore, this criterion includes an indicator, *CO_2 emissions* (I_3), which is a greenhouse gas and that, consequently, contributes to the greenhouse effect by absorbing and emitting thermal radiation. In the analysis of the lifecycle, the stages that were included were: (1) extraction of the materials, (2) manufacture of the element, (3) transportation to the sports hall.

The purpose of criterion C_4 is, on the one hand, to minimise the consumption of resources and, on the other hand, to account for the possibility of reusability of different materials, both at the construction and at the decommissioning stages. For this, three indicators are proposed: *energy* (I_4), *water* (I_5) and *material* (I_6).

- The assessment of indicators I_4 and I_5 is direct and considers the same stages of the lifecycle as indicator I_3.
- As for indicator I_6, its main purpose is to consider the amount of each material that is used and also the inherent characteristics. Therefore, for its evaluation three different sub-indicators were defined: scarcity of the raw materials, recycling potential and potential for using recycled materials. These variables were adapted from Harris (1999) and Vefago and Avellaneda (2013) to the present project. In order to obtain I_6, the total points given to each sub-indicator are directly aggregated. The indicator since it has been proved that by considering each sub-indicator separately would produce the same results but would add more complexity to the model. This indicator provides a number between 2 and 9.
  – The scarcity of the raw materials permits to consider the availability of the materials used for the production. In case of high availability, the indicator scores 0; on the contrary, if the material availability is compromised or its renewability is low, the indicator scores 1 (Wagner, 2002).
  – Concerning materials' recycling, Gao et al. (2001) define a recycled building material as the "material which can be remade and reused as a building material after the building is disassembled". Vefago and Avellaneda (2013) consider that the materials that reach the lifecycles at least once can be classified into four different groups: recycled materials, which are those materials that maintain the initial properties but these do not need to serve the same function in the next life cycle; infracycled materials, whose initial properties decrease and therefore do not need to serve the same function in the following life cycle; reused materials, which maintain the initial properties and do not need to serve the same function afterwards. Differently to recycled materials, reused materials do not pass through any chemical transformation or changes in their physical state and these have the same performance in the following cycles. Finally, the processes that infraused materials undergo have the same characteristics as reused materials, but their initial properties decrease and these cannot serve the same function as these did in the previous lifecycle. Therefore, the recycling potential seeks to evaluate the extent to which the materials can be used after the lifecycle ends. The indicator was calibrated by scoring from 1 to 5 depending whether the material can be used as landfill, it can be infraused, infracycled, recycled or reused, respectively.
  – As for the potential for using recycled materials, the sub-indicator assesses whether the alternative considered can make use of previously used materials, and the sub-indicator was scored between 1 and 3. The scoring of these sub-indicators was made according to Berge (2000), Thormark (2006), Vefago (2011), Vefago and Avellaneda (2013) and Akanbi et al. (2018).

7.3.2.3. Social requirement

The social criteria that were fixed in this model are two: *perception* (C_5) and *safety* (C_6). Firstly, criterion C_5 aims at measuring how well the structural element adapts to its context and how it is perceived by its users and the local community. This first criterion encompasses four different indicators: *user's comfort* (I_7), *context adaptability* (I_8), *construction time* (I_9) and *installations* (I_{10}).

- *User's comfort* (I_7) covers four areas: acoustic comfort, slenderness, warmth of the material and light. These areas were chosen following the research carried out by several authors about the impact on individuals' perception of materials and shapes:

  - Firstly, different materials have different acoustic properties; in a building that is occupied and where a high level of sound can be reached, which is the case of sports halls, the discomfort that occupants face needs to be considered. Factors that have been considered in the analysis of the acoustics of materials are its massiveness, density and rugosity (Ijatuyi et al. (2007), Rilo et al. (2002)). The acoustic comfort in this study was measured giving a score between 1 (lowest comfort) and 3 (highest comfort).
  - Secondly, another aspect to be considered is the aesthetics of the structural element itself. Some authors have proposed measuring the visual impact by computing the slenderness of the element (Menn, 1990). To this end, these authors proposed calculating a slenderness ratio, which is obtained by dividing the span length of the element by its height. This research assumed this approach. The slenderness ratio is used to obtain the value of the indicator, this ranging between 1 and 3. In this regard, for slenderness ratios between 0 and 7, the element is considered to have excellent aesthetics quality and therefore a score of 3 is considered; for ratios between 8 and 14, the alternative is given a 2; and for ratios higher than 14 it is given a value of 1.
  - Thirdly, the warmth of construction materials has been widely considered by architects, who argue that it's a property that highly influences user's experience in buildings (Fleming (2014), Fujisaki et al. (2015), Tiest (2010), Wastiels et al. (2012, 2013), Wilkes et al. (2016)). In the previous sub-indicator, the visual impact of the element was measured only on the basis of its shape. Now, the visual impact is measured through the material. The warmth of the material seeks to measure how the users will visually perceive and experience the different materials. Again, the score between 1 and 3 is used to evaluate this sub-indicator.
  - In the fourth place, light in the interiors of buildings has been considered by many as an important aspect contributing to feelings of well-being (Jakubiec (2014)). Even though there exist specific metrics for the measurement of visual comfort prediction, in this study a more simplified method was used because it has been considered that more complex methodologies would not add more accuracy to the results given the weight of this sub-indicator with respect to the overall index. Therefore, a score between 1 and 5 has been assigned depending on whether light can or cannot go through the structural element respectively. This sub-indicator is also considering what Menn (1990) calls the structural transparency. In the end, indicator I_7 ranges between 4 and 14 as a result of adding up the four constituent sub-indicators.
- The second indicator, *context adaptability* I_8, aims at measuring the level at which a structural element can be customised in order to adapt to local characteristics, such as a region's emblem. It is measured using a score between 1 and 3 (corresponding to not adaptable and totally adaptable respectively).
- Indicator I_9, *construction time*, measures the degree at which a longer duration of a construction process can negatively affect how it is perceived, and vice versa. It is measured from 1 (long duration of the process) to 3 (short duration).
- The fourth indicator, I_{10}, is a measure of whether service elements such as pipes that need to be set up in the roof can easily be installed through the structural element. This has been considered for two reasons: first of all, because it can affect the aesthetics of the building's interior; secondly, because it can introduce difficulties in the construction process. The indicator is measured from 1 (hardly installed) to 3 (very easily installed).

The criterion adopted for *safety* (C_6) is comprised of two indicators: *safety during construction* (I_{11}) and *safety during service* (I_{12}). It must be noted that structural safety during construction and service is considered as covered by applying the design regulations. In this sense, all the alternatives have the same structural safety. However, the purpose of these indicators is to evaluate the risks involved during handling in the construction and service stages of the structural elements. Both indicators are scored in a scale between 1 and 3 corresponding to low, medium and high levels of safety. The scoring of these attributes was made on the basis of the ranking scale proposed by Casanovas et al. (2014). It must be noted that the same ratings as in the publication were not used, but only adopted as a guideline to score the different alternatives in the mentioned interval.

7.3.2.4. Value functions and sustainability index

For the quantification of the established indicators, value functions (see Table 7.1) were established and calibrated. In this table, the shape of the value functions is described as decreasing S-shaped (DS), increasing linear (IL) and decreasing linear (DL). In the cases of those indicators that are measured in points, only integer values are possible.

7.3.3. Alternatives analysed

7.3.3.1. Selection of alternatives for the study case and system boundaries

For the study case, sports halls have been chosen due to the fact that one-storey frames constitute versatile building options for a wide range of purposes. In order to select the alternatives to be analysed, an initial study was conducted. To this aim, information on a total of 444 sports halls in the region of Catalonia was gathered. The buildings were classified according to the girder's material and structural typology used for supporting the roofs. The materials found were steel, concrete and timber and the structural typologies included both trusses and girders. The span length of the building was also a classifying parameter. The Catalan Sports Council establishes that there are mainly three types of sports halls depending on the dimensions of the sports courts, whose width can be of 20, 23 or 28 m (according to the regional regulation, defined by the Consell Català de l'Esport). In the present analysis, a building with a span of 28 m has been chosen.

The alternatives to be assessed were selected on the basis of the following criteria: (1) whether they were representative of all the existing structural typologies, not only at national level but also in a more general geopolitical context; (2) whether it was particularly interesting to study those since the performance in terms of sustainability is still not well understood. In the present study, this is the case, for example, of concrete trusses.

For the LCA, a cradle to operation approach has been adopted. Therefore, the stages that have been considered are the following: (1) extraction of the material and production; (2) production of the structural elements; (3) transportation to the construction site; (4) installation of the structural element; (5) basic maintenance during the service and operational life of the element, which has been considered to be of 50 years. Note that depending on the alternative considered, the order of steps (2) and (3) might change due to practical reasons. The decommissioning stage was considered not to be a determining factor in the evaluation of the structural elements studied since a simply supported configuration with no continuity and connections with the columns was assumed. This structural configuration, which is the most representative for these elements, facilitates the dismantling of the girders after the service life. A second use of the elements can be considered in case of inspections confirm that durability and/or fatigue problems are negligible or inexistent; otherwise, the girders must be treated in a recycled plant accordingly. Should this last process prove to be determining, an additional indicator could be included into the decision-making process.

A 28 m-span girder or truss was considered a functional unit, as it is a common size of three-court sports halls with spectators' stands in different countries. Reinforced or prestressed concrete, steel and timber were the structural materials considered for the construction of these elements. The structural elements were designed according to the Eurocode standards of each material: EC-2 (EN 1992-1-1 2004) for reinforced/prestressed concrete, EC-3 (EN 1993-1-1 2005) for steel and EC-5 (EN 1995-1-1 2004) for timber. Therefore, the design considered the Serviceability Limit State (SLS) and Ultimate Limit State

(ULS) of each of the alternatives. Hence, the loads (permanent and live loads) to be considered and the partial safety factors applied to both loads and materials' strengths are consistent with a unique safety format.

It must also be emphasised that the roof is non-accessible and, therefore, the design loads are only those associated to environmental aspects (snow, wind and thermal gradients) and other transient loads (repair, maintenance). Some of the parameters involved in the design are dependent on specific local or regional characteristics; concerning this, the location of the structure in the present study case is set in Vila-seca. It is a town in the province of Tarragona, in Catalonia, Spain. The location can easily be accessed by road. Finally, in terms of durability, the service life exposure conditions have been determined from the average ones according to Janjua et al. (2019), and no special treatments or additional measures, except the minimum expected maintenance, are considered.

7.3.3.2. Alternatives studied

After carrying out the analysis, seven alternatives resulted to be representative. Table 7.2 shows all the alternatives that were considered, as well as those that were finally chosen (in blue). A code was given for each alternative, the first letter referring to the material and the following letters correspond to the structural typology. Table 7.2 also shows the percentages with respect to the total that each alternative represents.

Table 7.2. Alternatives considered and chosen (in blue) in the study case

Material	Structural type	Code	Percentage (%)
Steel	Flat truss	SFT	35.78
	Sloped truss	SST	22.84
	3D truss		10.78
	Beam		13.36
Concrete	Truss	CT	0.86
	Beam		3.88
	Lightened prestressed	CLP	2.59
	Prestressed	CP	2.16
Timber	Beam	TB	6.89
	Truss	TT	0.86

As it can be seen in Table 7.2, three structural typologies were disregarded for the analysis. First, as for 3D trusses, it has been established that plane frame structures are those considered in this research. One of the advantages reported by several authors respect to spatial trusses there is the aesthetic quality (Bradshaw et al., 2002, Li, 1997). In this regard, three-dimensional trusses are preferred in those sports halls that seek to improve aesthetics and sense of place through more complex architectural structural elements which use can be justified in sports centres with flexible use and meant for gathering several thousands of people. Therefore, these structural elements are found to be unrepresentative of the general setting found in sports facilities for providing service in towns and villages, which are contrarily greater both in number and, consequently, in impact to the sustainability. Thus, standard alternatives were analysed in this thesis.

Secondly, steel and concrete girders were disregarded because the span-length range of the sports' halls chosen is scarcely technically-economically compatible with these alternatives. Specifically, mentioned girders, with the considered span and the kind of structural supports' hall, do not meet of the service limit states of cracking and deflection. In spite of the dismissal of these three structural typologies, the representativeness is still high and corresponds to 72% of the total. The dimensions and detailing of the alternatives that have finally been considered in the study case are shown in Figures 2 (steel structures), 3 (concrete structures) and 4 (timber structures).

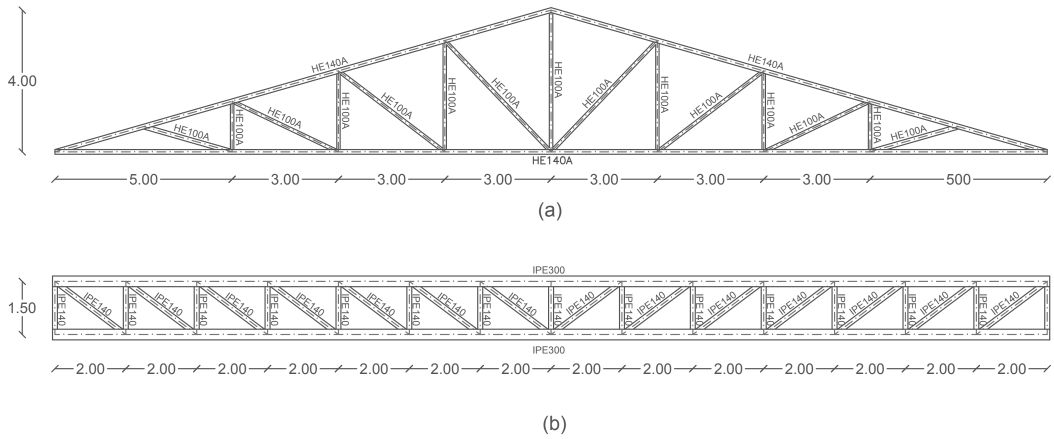

Figure 7.2. Detailing of the design of the (a) sloped steel truss and (b) flat steel truss (the measurements are shown in metres)

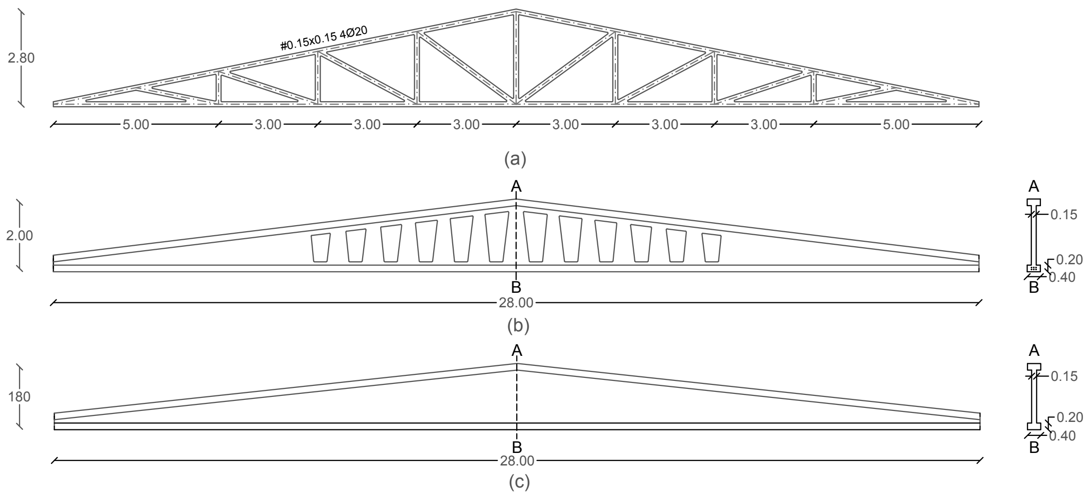

Figure 7.3. Detailing of the design of the (a) concrete truss, (b) lightened prestressed concrete girder and (c) prestressed concrete girder (the measurements are shown in metres)

As for the production of each alternative, the following situations have been considered. It has been assumed that the prestressed concrete beams and the timber beam are produced in a factory and transported to the construction site using special transportation. Regarding the steel trusses and timber truss, it has been considered that their components are produced in the factory and partially assembled so that no special transportation is required, which usually involves requesting a special permit and paying extra costs. The assembly of the remaining parts to be joined is carried out on site. In the case of the steel trusses, all the welding processes are considered to be performed in the factory while the parts left to the assembly in situ are joined using bolts. Finally, the concrete truss has been considered to be completely manufactured in the construction site. With respect to the maintenance, the maintenance works for each of the structural elements have been decided as: a visual inspection every five years starting from the tenth year, as well as a superficial anticorrosion treatment every fifteen years for the steel trusses; a visual inspection every two years for the prestressed beams; a visual inspection every ten years starting in the second year for the concrete truss; an annual visual inspection for the timber truss and beam.

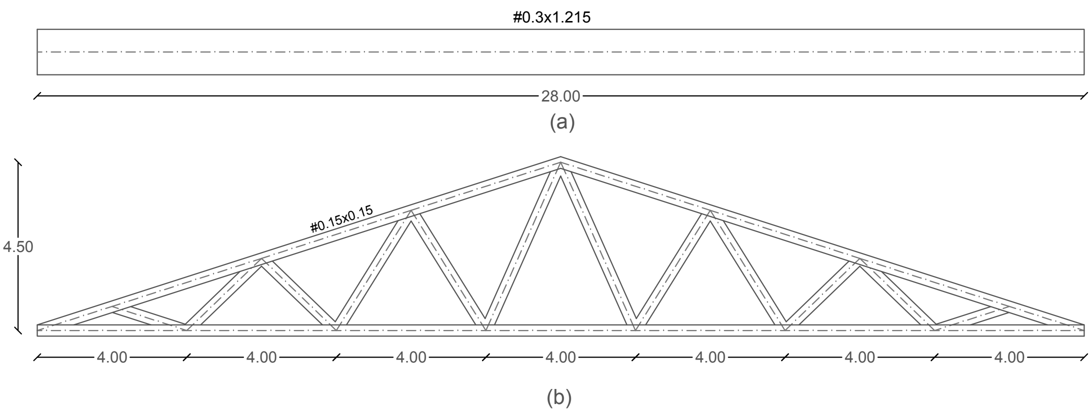

Figure 7.4. Detailing of the design of the (a) timber beam and (b) timber truss (the measurements are shown in metres)

7.3.4. Results

Table 7.3 shows the quantification of the twelve indicators (I_1 to I_{12}) for each of the alternatives analyzed. In order to obtain the results, the value (seen as satisfaction) of each of the indicators is computed with the respective value function, which yields the final values of the indicators.

Table 7.3. Values of the indicators corresponding to each alternative

		Steel		Concrete			Timber	
	Units	**SFT**	**SST**	**CP**	**CLP**	**CT**	**TT**	**TB**
I_1	€	3246.62	2349.25	7861.03	6390.19	1449.22	3144.64	9345.24
I_2	€	14.0	15.5	5.3	5.3	2.3	22.6	19.0
I_3	kg CO_2	12472.71	8784.79	3267.88	2141.93	1478.08	79.24	367.82
I_4	MJ	129404.35	91142.16	76849.17	73627.58	62803.10	2770.30	12859.56
I_5	m3	8.42	5.93	1.80	1.66	0.43	0.05	0.02
I_6	points	9	9	3.5	3.5	5	4.5	5
I_7	points	10	9	10	10	10	11	10
I_8	points	3	3	1	1	1	1	1
I_9	points	3	3	2	2	2	3	1
I_{10}	points	3	3	1	2	3	3	1
I_{11}	points	2	2	3	3	1	1	1
I_{12}	points	3	3	1	1	2	2	2

Figure 7.5 gathers three graphs representing the overall weighted indexes of the economic, environmental and social requirements, as well as the contribution of each of the criteria to the total requirement.

Concerning the environmental requirement, the lowest values are attained by the steel trusses, whereas the highest ones correspond to the elements made with timber. Specifically, the TT results in an increase of the requirement by 58% and 67% over STF and SST respectively. Even though steel is environmentally appealing due to the fact that almost the totality of the material can be recycled, its production generates a high amount of CO_2 emissions and consequently both steel alternatives score very poorly in criterion 3. Additionally, the amount of water necessary for its production is relatively significant in comparison to timber and concrete. As for CP, CLP and CT, these achieve middle values that represent a decrease in the environmental requirement of 47%, 39% and 28% over TT respectively.

Finally, with regard to the social requirement, both steel trusses present the highest indexes, notwith-

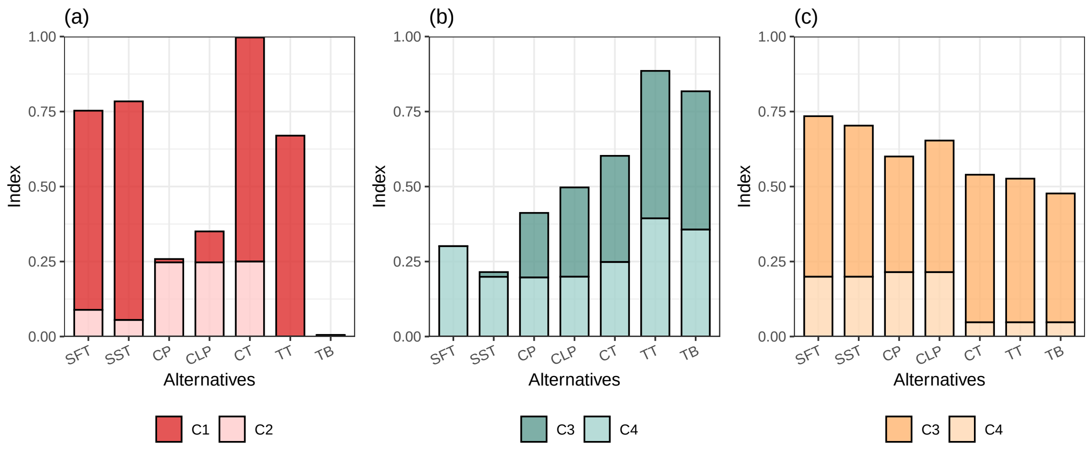

Figure 7.5. Results of the analysis for the economic (a), environmental (b) and social (c) requirements of each alternative

standing it needs to be emphasised that in this case the dispersion of the requirement (σ = 0.099) is much less than in the economic and environmental cases (σ = 0.349 and σ = 0.256 respectively). In fact, the proportional increase in the value of the social requirement from TB, which has the lowest score, to SFT is of a 26%. Trusses are the elements that achieve highest values of criterion 5, this owing to the fact that these score higher in terms of light in the interior of the building.

Concerning the global sustainability index (SI), the values of each of the alternatives are shown in Figure 7.6. In the light of the results, it can be seen that the maximum index is obtained by the timber truss (SI = 0.71), albeit its index is closely followed by the concrete truss with a 1% difference (SI = 0.70); next to these alternatives the flat steel truss (SI = 0.57) and the sloped steel truss (SI = 0.53) achieve the third and fourth highest indexes, even though again both values are quite similar; the three last alternatives are the lightened prestressed concrete, the timber beam and the prestressed concrete, with SIs of 0.50, 0.47 and 0.42, respectively. Therefore, the TT respectively represents an increase of 21%, 24% and 29% over these alternatives. Nevertheless, the robustness of the results needs to be examined in view of the fact that there might be uncertainties. Mainly, the concrete and the timber trusses achieve very similar SIs values; the same occurring with both steel trusses and with the prestressed concrete and the timber beams. The sensitivity analysis is described in the following section.

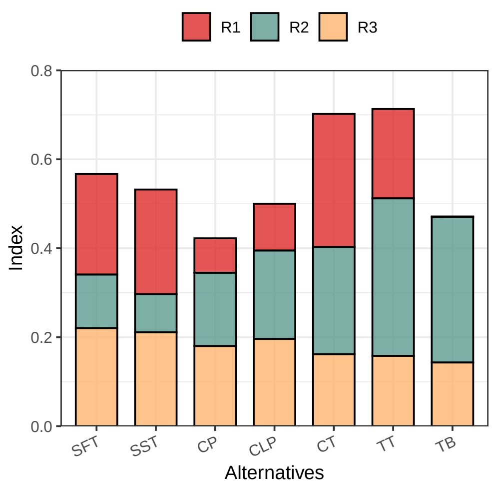

Figure 7.6. Global sustainability index obtained for each alternative

7.3.5. Sensitivity analysis

In order to check the robustness of the results, a sensitivity analysis was carried out. Some authors assessing sustainability through indexes perform the sensitivity analysis by contemplating only a few cases which differ by the weights given to each requirement. See, for example, De La Fuente et al. (2016). However, del Caño et al. (2012) and Cartelle Barros et al. (2016, 2015) recommend using more complex statistical techniques when the results of the alternatives are tighter, which is what characterises the present study. On account of this fact, the Monte Carlo method was resorted to approach the problem probabilistically. Monte Carlo is based on the stochastic simulation done by repeating multiple times an experiment, so that a numerical approximation is found as a solution to the initial problem. In these simulations, it is necessary to produce a large enough quantity of random numbers as inputs, which can afterwards be used in order to estimate their respective outputs for the model. As del Caño et al. (2012) describe, to apply the method, it is necessary to define the distribution functions of those values treated probabilistically. Once these are defined, then the next phases cover the simulations: generating pseudo-random values and evaluate the model with the obtained values. Finally, it is possible to obtain a frequency histogram of SIs, as well as its cumulative distribution function. This last curve allows to better understand and interpret the results of the statistical analysis.

For the present study two probabilistic scenarios have been considered. The first one admits uncertainties in the data, whereas the second one has the uncertainties in the weighting system. In both scenarios the constitutive parameters of the value functions were maintained as originally defined. In both cases, the convergence of the results was controlled by dynamically checking that the coefficient of variation of the mean index was below 0,001 a hundred consecutive times. The maximum number of iterations set for this study was 500,000.

7.3.5.1. Scenario 1

The uncertainties in the data were established by using the different values of each of the indicators that have been obtained from consulting the databases. The beta PERT distribution, which provides a smoother variation of the density of probability from the mode to the extremes in comparison to a triangular distribution, was assumed as representative. This consisted of the following parameters: the minimum and maximum values of the indicator and the mode of the data.

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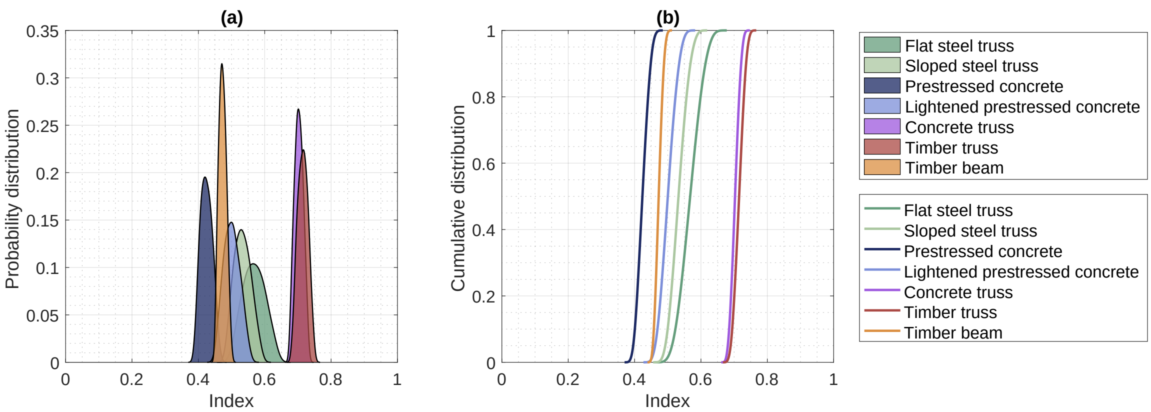

Figure 7.7. Probability distribution functions (a) and cumulative distribution (b) for the sustainability indexes with uncertainties in the indicators

7.3.5.2. Scenario 2

As for the uncertainties in the weights, a ±10% was assumed to cover properly the uncertainty of the weights initially calibrated within the experts' seminars, this being the mode of the population. When considering the weights of the requirements as probabilistic, attention must be paid to the sum of the pseudo-random weights, since it is necessary that they add up to 100% (Cartelle Barros et al., 2016). Therefore, in each iteration the values of the weights were normalised and in case extreme cases occurred, new pseudo-random values were generated.

Regarding the second scenario, where uncertainties were introduced through weighting system, the results are shown in Figure 7.8. It can be seen in Figure 7.8 that, again, the ranking in terms of SIs is maintained for all the alternatives, the order being the following: timber truss, concrete truss, flat steel truss, sloped steel truss, lightened prestressed concrete beam, timber beam, prestressed concrete

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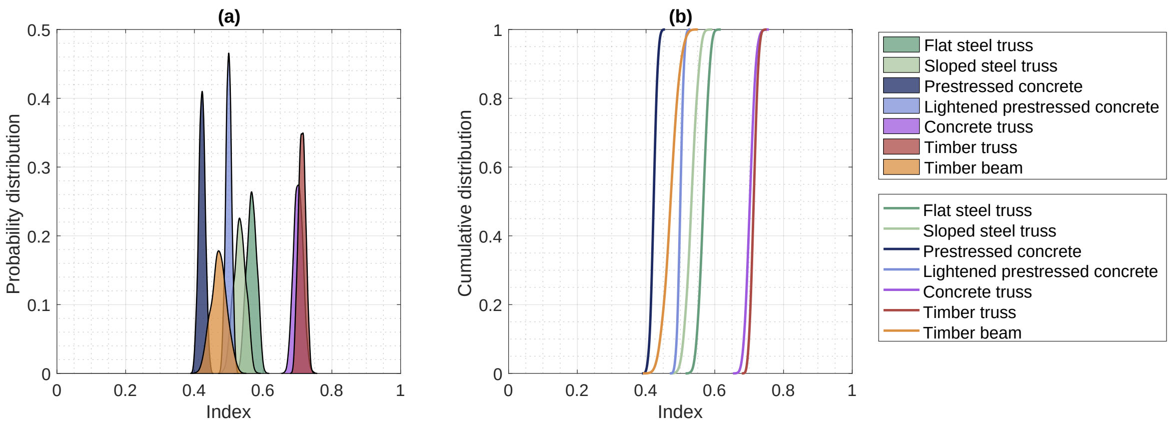

Figure 7.8. Probability distribution functions (a) and cumulative distribution (b) for the sustainability indexes with uncertainties in the weighting system

7.3.6. Conclusions

In this section, a multi-criteria model for sustainability assessment based on the method MIVES has been proposed. The model can be used to assess the sustainability of structural elements of different materials. Particularly, the developed model has been used to assess the sustainability of structural truss and girders made with different materials for non-accessible roofs of sports halls. This has been done by considering three requirements, six criteria and twelve indicators. The study case consisted of seven alternatives, namely: a flat steel truss, a sloped steel truss, a prestressed concrete girder, a lightened prestressed concrete girder, a concrete truss, a timber truss and a timber girder. The results obtained in this section may be of interest to practitioners that deal with structural design oriented to sustainable solutions for sports halls, industrial buildings or warehouses. It must be emphasised that the available sustainability rating tools and certifications barely cover structural elements as an independent part of the structure and, therefore, important features and indicators that affect sustainability can be missed.

Additionally, the development of the model can be proposed as an activity to students of structural analysis and design courses. Students may be asked to develop the full analysis presented here, or parts of it, depending on the course requirements and learning outcomes sought for the activity. This activity provides a wide range of opportunities of learning, such as fostering critical thinking through the analysis of what the "best" alternative is. In this case, as for the requirements, economically the best solution was the concrete truss. The alternatives achieving highest indexes were the timber beam and truss. Nonetheless, socially, all the alternatives yielded very similar results, the steel alternatives being slightly better. As for the global sustainability index, the differences of the index's value of the timber and reinforced concrete trusses and of the timber and prestressed concrete girders were not significant. Related to this, students may also want to question the reasons why the most sustainable options are those being the least used.

Besides, it is worth to note that timber is usually seen as one of the most sustainable construction materials, albeit this can be misleading. The results of the analysis show that, even though timber is environmentally friendly, it can be an economic stressor depending on the structural element for which it is used. Particularly, the analysed glue laminated timber truss performs well in terms of sustainability; on the contrary, the timber girder is ranked as one of the worst options due to the high costs of its production. Regarding concrete, even though it has a negative perception among society, it can actually be a sustainable alternative as the results for concrete truss show. Currently, concrete trusses are not being used as a structural alternative in roofs, while steel trusses are widely used; this is in spite of the fact that actually the former perform well in terms of sustainability in contrast to the later.

7.4. Integration of the "social" in a materials course

The second application of a MCDM model as a class activity is in the context of materials science. In the following sections, the context of the study, the model developed and the results and discussion are presented.

7.4.1. Context

Water is basic for humans. This has been reflected in many internationally recognised documents such as the resolution adopted by the United Nations (UN) (UN General Assembly, 2015). Through this resolution, the UN recognised the human right to water and sanitation and acknowledged that clean drinking water and sanitation were essential to the realisation of all human rights.

Besides, this resolution also emphasised the role of institutions in helping capacity-building and technology transfer to support countries that do not have clean, safe, accessible and affordable drinking water and sanitation for all. Furthermore, the relationship between WaSH (Water, Sanitation and Hygiene) and economic, environmental and social factors has been increasingly recognised as an important component within lifecycle thinking and the sustainable development framework (UN General Assembly, 2015). This has been transferred to the 2030 Agenda for Sustainable Development, which determines issues related to water and sanitation to be fundamental. Setty et al. (2020) identify the current priority areas in the field of WaSH and in relation to meeting Sustainable Development Goal 6 (SDG 6). In particular, at present, development of sanitation and wastewater networks is a major challenge in many countries as this has a strong connection to aspects such as health, nutrition, education or poverty eradication Requejo-Castro et al. (2020), WHO and UNICEF (2016).

Whilst some research has been carried out in different areas related to SDG 6, there is a gap in scientific understanding of wastewater infrastructure from a sustainability point of view. In this context, piping systems are crucial elements Nilsson (2006), Ranganathan et al. (2009). Although sometimes overlooked, these are essential in the urban water cycle as a mainstay of wastewater treatment. Design is particularly important, as underground sanitation networks tend to be difficult to access.

Sewerage pipes can be divided into flexible and rigid, according to the relative soil-pipe stiffness De La Fuente et al. (2016). The former are frequently made out of steel or thermoplastics (e.g. polypropylene, polyethylene, PVC), whilst the latter are made out of concrete (either plain or reinforced). Thermoplastic pipes are usually designated for pipes with internal diameters under 300 mm, whereas concrete pipes (CPs, hereinafter) are more often produced for diameters ranging between 300 mm and 3000 mm.

Traditionally, unreinforced concrete pipes (UCPs) and steel-bar reinforced concrete pipes (RCPs) have been two predominant alternatives when designing sewerage and drainage pipes. However, more recently, fibre-reinforced concrete pipes (FRCPs) emerged as a viable alternative. The introduction of structural fibres in this context was mainly due to their technical and economic advantages De La Fuente et al. (2012), Figueiredo (2008), Haktanir et al. (2007). In fact, numerous publications address and compare technical specificities concerning different concrete pipe configurations. Some examples are (1) determination of optimal fibre content according to the required strength class de la Fuente et al. (2011), Mohamed and Nehdi (2016); (2) mechanical properties and design of steel Abolmaali et al. (2012), Coombs et al. (2013), de la Fuente et al. (2012), De La Fuente et al. (2012), Mohamed et al. (2014), Monte et al. (2016), Mu et al. (2019), Song and Hwang (2004) and polypropylene CPs Al Rikabi et al. (2019a), De La Fuente et al. (2013), Lee et al. (2019), Park et al. (2014), Wilson and Abolmaali (2014); (3) fibre hybridisation Amirpasha Peyvandi and Shervin Jahangirnejad (2014), Lee et al. (2019) and the combination of steel cages and fibres Al Rikabi et al. (2019b), Park et al. (2015a,b); (4) the long-term performance under boundary loading conditions Al Rikabi et al. (2019a), Nehdi et al. (2016), Park et al. (2014); (5) computer-aided design Amirpasha Peyvandi and Shervin Jahangirnejad (2014), Doru (2017), Heger (1963), Mohamed et al. (2015), Pedersen et al. (2017); and, (6) analysis of damage evolution when in service Pour-Ghaz et al. (2018). Nevertheless, it is essential to better understand the sustainability implications that the use of different reinforcements have. In fact, until the present, the choice of reinforcement is at present primarily cost-driven, and does not consider other fundamental aspects that are currently disregarded (or subjectively taken into account). These other factors include risks during pipe manufacturing and handling; recyclability of the concrete mix constituents; emissions and embodied energy associated with the production of the reinforcement and social perceptions.

Currently, no comparative studies exist on sustainability of concrete pipes with different reinforcements. It is in this context that decision-making methods may be useful to support production and installation of more sustainable piping systems, not only economically or functionally, but also environmentally and socially. This said, it should be mentioned that sustainability assessment studies in the civil engineering field have tended to focus more on comprehensive analyses rather than on specific structural components. Nevertheless, this is starting to shift towards more studies focusing on specific components within a structure De La Fuente et al. (2019), Josa et al. (2020). Analysis of specific structural elements (e.g. columns, beams, and slabs of a building) provides understanding on how a specific part of a system contributes to overall sustainability. Besides, it can also be valuable in maintenance stages, where specific parts of a structure need to be replaced.

Against this background, the method MIVES, is a multi-criteria decision-making method that provides support for product and service sustainability assessment. It has already proven to be a suitable approach to assist stakeholders in decision-making processes where sustainability is a key determinant, such as hydraulic De La Fuente et al. (2016), Pardo-Bosch and Aguado (2015) and underground Alberti et al. (2018b), de la Fuente et al. (2017a), De La Fuente et al. (2012) infrastructures; buildings De La Fuente et al. (2019), Pons and Aguado (2012), Pons and De La Fuente (2013), Pons et al. (2016); industrial construction San-José Lombera and Garrucho Aprea (2010); urban development Pujadas et al. (2017); electricity generation infrastructure Cartelle Barros et al. (2015), de la Fuente et al. (2017b); and, even, post-disaster housing management and reconstruction Amin Hosseini et al. (2016), Hosseini et al. (2016). It should be mentioned that MIVES was included into the fib Bulletins 83 “Precast Tunnel Segments in Fibre Reinforced Concrete” (Fib, 2017) and 88 “Sustainability of Prefabrication” (Fib, 2018) as a reference model to assess sustainability in the field of precast concrete products.

Therefore, this study makes use of the flexibility of MIVES to simultaneously develop a tool to assess the sustainability of structural concrete elements in the context of WASH and to compose a decision-making tree based on the MIVES method to assess the sustainability of concrete pipes. In particular, the main contributions of the article are threefold. First of all, it proposes and applies a model for the case of concrete pipes; this model can easily be adapted for other case studies. Secondly, it determines how different typologies of pipes contribute to the overall sustainability of infrastructure systems, which can be useful for practitioners and researchers. Thirdly, it presents the application of a multi-criteria decision-making methodology, which is potentially relevant for other researchers to better understand how it can be used and applied.

7.4.1.1. Concepts

The mechanical performance of CPs is characterised by means of the three-edge bearing test (TEBT), following procedures set in any national standard (e.g. EN 1916:2008, 2008 in Europe or ASTM C497-19a in the USA). This test procedure has been accepted worldwide owing to the representativeness and robustness of its results, among other features Carleton et al. (2017).

Concrete reinforcement has been provided since the early 1900s Carleton et al. (2017), Marston and Anderson (1913) by steel-cages, requiring either manual labour and/or special equipment to curve and weld rebars. This reinforcement strategy dominates the market due to the competitive cost of steel and the standardisation of production processes; likewise, the geometry of these cages means that the structural response of the RCPs can be optimised.

Nonetheless, steel is prone to corrosion and degradation under the severe environmental conditions to which CPs are exposed. In this regard, controlling and imposing minimum concrete cover for steel bars and maximum crack width under loading conditions is of paramount importance to guarantee the expected service life (50-100 years).

Although there are structural reliability-oriented measures (e.g. use of global safety coefficients and strict quality controls), these parameters are subject to uncertainties due to acceptable manufacturing tolerances and variability associated with service loads and soil-pipe interaction conditions as well as inaccuracies in the design hypotheses. This variability leads to accepting a certain likelihood that the concrete cover and crack width values will be thinner or higher, respectively, than expected. This may jeopardise the pipeline durability Vu and Stewart (2005).

During the late 1990s and early 2000s, steel fibres (SFs) emerged on the concrete pipe market as an attractive alternative to completely replace steel-cage reinforcement in RCPs for diameters up to 1000 mm Monte et al. (2016). SFs have proven to be a cost-effective solution since the processes associated with steel-cage production and the space it requires for stacking (significant in plants with intense production) can be reduced. From the mechanical performance point of view, extensive experimental research has demonstrated that using the proper type and amount of SFs can lead to reinforcements less prone to deterioration because fibres are more efficient in controlling crack widths Peyvandi et al. (2013a,b). However, attention must be paid to operator safety during handling since SFs are rigid and any remaining on the outer surface might cause injuries.

More recently, polymeric fibres (PFs) are being introduced into the CP market as the mechanical properties (modulus of elasticity and tensile strength capacity) of these fibres have been largely enhanced and they can compete technically with steel reinforcements up to certain pipe diameters and pipe strength classes. This is particularly evident when durability aspects govern pipeline serviceability and maintenance as PFs are resistant to corrosive and chemically damaging environments Hannant (1998), Richardson (2004). To the authors' best knowledge, only the ASTM C1765-19 ASTM C1765-19 permits the use of polymeric fibres, only for non-structural proposals, most probably due to lack of sufficient evidence on the adequate long-term response of PFRCs when the existing guidelines were under discussion. Nonetheless, since then, extensive experimental research has been carried out on PFRCPs Al Rikabi et al. (2019a), De La Fuente et al. (2013), Lee et al. (2019), Park et al. (2014), Wilson and Abolmaali (2014), even combining steel cages and PF fibres Al Rikabi et al. (2019b), Park et al. (2015a), confirming the adequate response of these pipes under permanent loading conditions Park et al. (2014).

7.4.2. Selection of alternatives

For this analysis, internal pipe diameters (D_i) of 300, 600 and 1000 mm were considered along with the two alternative wall-thicknesses (type B or C, which correspond to two different thicknesses according to UNE 127916 UNE 127916 (2017)) per pipe diameter. As for the pipe strength class, the C60, C90, C135 and C180 classes were included, the number representing the failure load (F_n) to be achieved in the TEBT.

In this regard, the distribution and amount of steel-cage reinforcement proposed in the Spanish Annex UNE 127916 (2017) of the EN 1916:2008 was considered in this study for RCPs EN 1916:2008 (2008). Other distributions, such as any proposed in the ASTM C76-19b ASTM C76-19b, can be used as an alternative. For the FRCPs, as no recommendations regarding the required type and amount of fibres to reach each pipe strength class are currently available, the MAP (Model for the Analysis of Pipes) design approach valid for SFRCPs De La Fuente et al. (2012) and for PFRCPs De La Fuente et al. (2013) is used instead.

This combination of parameters (3 diameters and 2 wall-thicknesses, 3 reinforcement configurations and 4 pipe strength classes per diameter) produced a total of 24 concrete pipes (Table 7.4).

7.4.3. Assessment model

Figure 7.9 shows the decision-making tree developed for the sustainability assessment (on the reinforcement configuration of CPs) including the economic, environmental and social requirements (UN General Assembly, 2015).

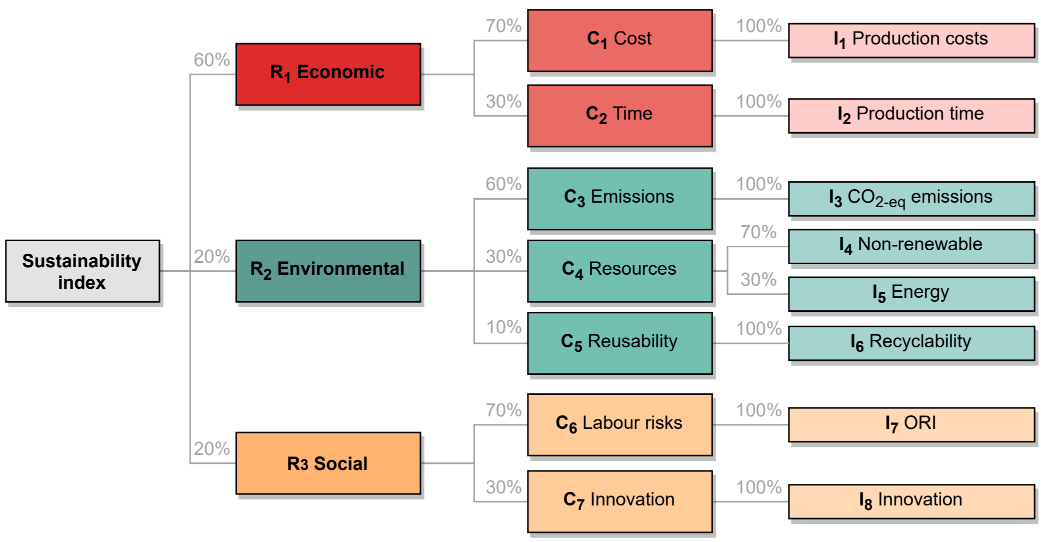

Figure 7.9. Decision-making tree model for the study case

The functional unit is 1.0 m of pipe considering that the analysis runs from the extraction and processing of the materials to the staking at the precast concrete plant yard. Consequently, transport, installation

Table 7.4. Parameters defining analysed alternatives.

Nº Ref.	Code	D_{int} (mm)	Thickness (mm)	Resistance class (kN/m^2)
1	**300/50/C60**	300	50 (B)	C 60
2	**300/69/C60**		69 (C)	
3	**300/50/C90**		50 (B)	C 90
4	**300/69/C90**		69 (C)	
5	**300/50/C135**		50 (B)	C 135
6	**300/69/C135**		69 (C)	
7	**300/50/C180**		50 (B)	C 180
8	**300/69/C180**		69 (C)	
9	**600/75/C60**	600	75 (B)	C 60
10	**600/94/C60**		94 (C)	
11	**600/75/C90**		75 (B)	C 90
12	**600/94/C90**		94 (C)	
13	**600/75/C135**		75 (B)	C 135
14	**600/94/C135**		94 (C)	
15	**600/75/C180**		75 (B)	C 180
16	**600/94/C180**		94 (C)	
17	**1000/109/C60**	1000	109 (B)	C 60
18	**1000/128/C60**		128 (C)	
19	**1000/109/C90**		109 (B)	C 90
20	**1000/128/C90**		128 (C)	
21	**1000/109/C135**		109 (B)	C 135
22	**1000/128/C135**		128 (C)	
23	**1000/109/C180**		109 (B)	C 180
24	**1000/128/C180**		128 (C)	

and operation impacts are disregarded since the reinforcement configuration does not entail any significant variation in the indicators being considered.

Regarding the operational stage, this assumption implies that the extension of the service life (regarding the design value, which is usually over 50 years), which could potentially be achieved through the use of PFs, is not considered. It should be noted that use of PFs is considered to have a positive impact on the three requirements; nonetheless, that extension is difficult to forecast at a technical level with the information currently available. Should this be possible, I_1 and I_3–I_5 indicators could be factored by the total expected years of service life to take this extension into account.

Regarding the relative importance of each requirement, the most weight was assigned to the economic requirement (60%), as the decisive driver in both precast industry and public/private sectors, while the remaining 40% was shared out equally between the environmental and social requirements. Although this is the tendency, this distribution might be contrary to other opinions in the context of sustainability (e.g., equal distribution of weights). For this reason, a sensitivity analysis of the sustainability index for each alternative will be carried out in the last subsection considering other sets of weights.

7.4.3.1. Economic Requirement

The economic requirement (R_1) consists in two criteria: cost (C_1) and time (C_2). Each criterion is measured by one indicator. In the case of C_1, the indicator used is production costs (I_1). The prices for transportation and assembly were omitted in this indicator since the different alternatives have the same costs. Both materials and processing labour costs are gathered using the I_1 indicator. The average costs of the concrete reinforcing alternatives considered herein are based on Spanish market prices in

2020. In particular, specific data were provided by a company producing CPs.

- RCPs: 0.75 €/kg for curved cages with grade B500S steel (including the manufacturing process).
- SFRCPs: 1.25 €/kg of a hooked-end steel macrofibre with $60 \leq \lambda f \leq 80$, where $\lambda = l_f/\phi_f$ is the aspect ratio, l_f the length, ϕ_f the diameter of the fibre, and with a tensile strength (f_{fu}) ranging from 1000–1200 N/mm^2 and modulus of elasticity (E_f) between 200,000–210,000 N/mm^2.
- PFRCPs: 4.00 €/kg of synthetic macrofibre with $40 \leq \lambda f \leq 60$, $500 \leq f_{fu} \leq 650$ N/mm^2 and $5000 \leq E_f \leq 9000$ N/mm^2.

The cost of a vibrated-compressed concrete strength class C30/35 ($f_{ck,cyl} = 30$ N/mm^2) was estimated as 51.5 $€/m^3$. This cost can be slightly higher when FRC is used since the composition is modified (granular skeleton and admixtures dosage) to guarantee that the mix is workable. This variation is, nonetheless, of minor importance in the total cost and omitted thereof.

Additionally, the cost associated with the finish (e.g., external surface polishing) is also included. This cost depends primarily on the outer pipe diameter (D_o) and varies linearly from 1.9 €/m ($D_o = 300$ mm) to 6.3 €/m ($D_o = 1000$ mm).

Finally, in the case of C_2, the indicator is total time (I_2). This I_2 indicator is included to quantify the time allocated for producing and assembling the reinforcing steel-cage (97 kg/h). In the case of RCPs, the time necessary for concrete production and vibration (1.68 m^3/h) is also considered. For FRCPs, the fibres are directly dosed and mixed with the remaining concrete components. The information necessary for this indicator was provided by experts working in the production of CPs.

7.4.3.2. Environmental Requirement

The environmental requirement (R_2) is comprised of three criteria: emissions (C_3), resources (C_4) and reusability (C_5).

On the one hand, Criterion C_3 is evaluated using a single indicator: equivalent carbon dioxide emissions (I_3). This indicator was obtained by considering the emissions of all the constituent materials of the pipe (concrete and reinforcing). On the other hand, Criterion C_4 consists of two indicators: non-renewable resources (I_4) and energy resources (I_5). The former is meant to assess the impact on the stock of existing resources considering its renovation capacity. To this end, the required weights of each pipe constituent are added together by applying an importance factor. This importance factor is based on the environmental profiles by Harris (1999) and the methodology by Kappenthuler and Seeger (2020) to consider the short and long-term availability of building materials. The data in OECD (2019), Wagner (2002) were examined to calculate these availabilities. The latter makes it possible to examine the embodied energy linked to the production and assembly processes for the pipe component elements. The inventory in Jones (2019) was utilised as a reference for assessing I_3 and I_5 indicators.

Finally, Criterion C_5 (reusability) is represented by one indicator, recyclability (I_6). This aspect is considered a key factor in many studies (see, e.g., Casanovas-Rubio et al. (2019), Harris (1999), Josa et al. (2020), Vefago and Avellaneda (2013)). While previous indicators in the environmental requirement considered the first stages of the lifecycle of the reinforcing alternatives, this indicator takes into consideration the final stage of the lifecycle, namely the decommissioning, and the recycling potential of each alternative. A building material that can be recycled is defined in Gao et al. (2001) as a "material which can be remade and reused as a building material after the building is disassembled". In this study, this indicator was evaluated through attributes by using a five-point scale based on experts' seminars as well as on other references Casanovas-Rubio et al. (2019), Harris (1999), Josa et al. (2020), Vefago and Avellaneda (2013). The details of drawing up this scale are shown in Table 7.5. Note that the table shows the levels assigned to Points 1, 3 and 5, which correspond to the Likert scale Likert

(1932). However, mid-values (i.e., 2 and 4) may also be assigned for hybrid reinforcements.

Table 7.5. Attributes and respective points assigned to the different levels of recyclability.

Level of recyclability	Attribute	Type of reinforcement	Points
Non-recyclable	Low	Steel fibres	1
Partially recyclable	Medium	Polymeric fibres	3
Completely recyclable	High	Steel cage	5

7.4.3.3. Social Requirement

The social requirement (R_3) is defined by two criteria: labour risks during pipe manufacturing (C_6) and innovation of the solution (C_7). Other aspects, such as creating jobs and inconveniences for society, were considered to be insignificant impacts in the context of this study. The occupational risks during manufacturing were assessed using the Occupational Risk Index (ORI) (I_7) defined in Casanovas-Rubio et al. (2014) according to Equation (7.5).

$$ORI = \sum ORI_i = \sum_i IR_i \times E_i = \frac{1}{1000} \sum_i (P_i \times C_i \times E_i) \quad (7.5)$$

where i is the risk associated with an activity and IR_i is the importance of risk i, defined as the probability that an accident (P_i) will occur when risk i is present, multiplied by the severity of the most probable consequence (C_i) and divided by 1000 to standardise it by the maximum risk possible. E_i is the total time (in hours) that the workers are exposed to the risk. The information for this time was obtained from CYPE Ingenieros (2021), which is a database that contains prices for the construction industry, as well as construction times for different structural elements.

CPs are manufactured mechanically but require some manual operations. The activities carried out during manufacturing were analysed from an occupational risk point of view, which led to detecting the risks presented in Table 7.6. The probability and consequences ratings of the first three risks have been directly obtained from Casanovas-Rubio et al. (2014), whereas those of the two last risks have been newly evaluated for the present research. The probability and consequences of the first three risks in Table 7.6 were evaluated for the construction work conditions and could be slightly lower for the CPs as these are manufactured in a factory with controlled activities.

Table 7.6. Ratings of probability, severity of the most probable consequence, and importance of the occupational risks in pipe manufacturing.

Risk - activity		P	C	IR
1	Collision with or trapping by a moving load due to its movement or detachment - mechanical load handling (other means of mechanical load handling)	1	20	0.020
2	Blows to upper and lower limbs - manual load handling (installation of reinforcing bars)	3	7	0.021
3	Burns - welding	1	7	0.007
4	Cuts, blunt trauma, and other injuries - work with hand tools (smoothing trowels in steel fibres)	3	1	0.003
5	Cuts, blunt trauma, and other injuries - work with hand tools (smoothing trowels in plastic fibres)	2	1	0.002

Criterion C_7 is assessed using the I_8 innovation indicator to promote the research and progress on new reinforcing systems for concrete pipes. Steel cages for RCPs have been used satisfactorily for more than 100 years, but fibres (even recycled) are emerging that are proving to be a technically viable alternative within a certain range of pipe diameters. However, the construction sector is reluctant to make changes, and, therefore, changes should be encouraged by using multi-criteria decision-making approaches based on sustainability that also recognise innovation. This indicator does not only account for innovation in terms of the reinforcement itself, but also for other aspects such as in technologies or other materials. Examples of these would be using bendable bars for reinforcement or improvements associated with the welding methodologies. The attributes of this indicator were assigned during experts' seminars.

7.4.4. Results

Figure 7.10 shows the sustainability indexes corresponding to the economic aspect. The results have been separated according to the resistance class. The different diameters of each alternative are shown through the x-axis, whereas the thickness is shown with different line types and the different reinforcement types are shown with different colours. The y-axis corresponds to the values of the sustainability indexes. Because the analysis is parametric and the indicators were expressed in relation to the RC alternative, the sustainability index for the RCPs is constant.

All the alternatives have been found to have economic sustainability indexes higher than 0.3, with the best results being achieved by the C60 resistance class alternatives. FRCPs seem to perform economically better for $D_i = 300$ *mm*, independently of the strength class (except for C135 and C180 wall type B). Likewise, FRPCs C60 with D_i up to 1000 mm and wall type B achieve higher economic satisfaction than RCPs. These results are aligned with current market practice where both FRCPs and RCPs are competing for low strength ($\leq C90$) classes and $D_i \leq 600$ *mm*.

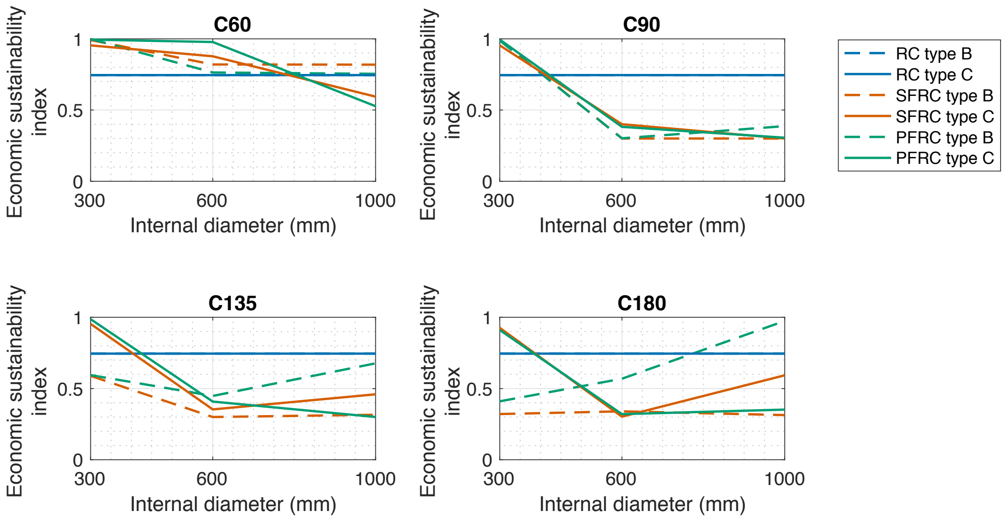

Figure 7.10. Economic sustainability indexes of each alternative.

Figure 7.11 shows the results corresponding to the environmental sustainability indexes. It should be noted that the PFRCPs lead to greater environmental performance with respect to RCPs and SFRCs for all diameters and strength classes. This is a consequence of the lower CO_2 emissions and embodied energy required to produce synthetic microfibres as well as the low amounts required to reach the target mechanical performance. SFRCPs show better tendencies in terms of environmental impacts with respect to the RCPs for strength classes inferior to C90 (included, except wall type C).

The results obtained for the social sustainability indexes, presented in Figure 7.12, highlight that FRCPs yield represent an enhancement (quantified in a 40%) with respect to RCPs in terms of social

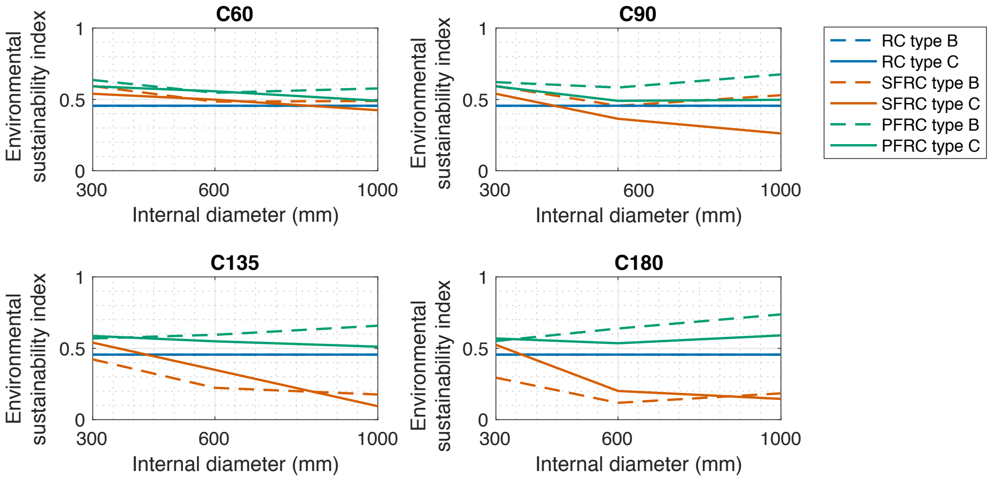

Figure 7.11. Environmental sustainability indexes of each alternative.

sustainability.

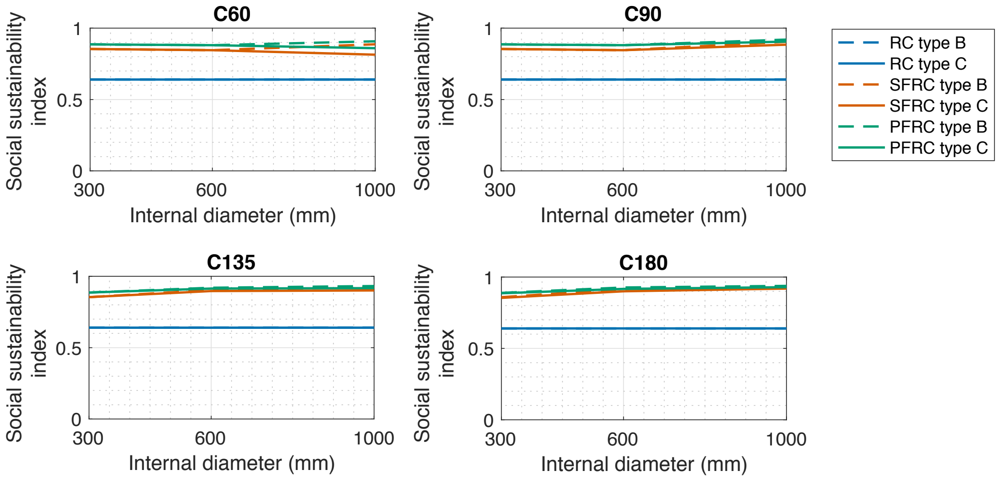

Figure 7.12. Social sustainability indexes of each alternative.

Finally, Figure 7.13 shows the results corresponding to the global sustainability indexes (I_s) of each alternative, which have been calculated by using the weighting system presented in Figure 7.9. From these results, it should be mentioned that FRPCs with $D_i = 300\ mm$ present a higher sustainability index with respect to the traditional RCPs, independently of the strength class (except wall type B for C135 and C180). Contrarily, as D_i and the strength class increase, the RCPs alternative is confirmed as the most suitable.

7.4.4.1. Value functions

value functions were assigned to each indicator (I_{ind}), thereby transforming physical units of each indicator (e.g., €/m, kg/m, $kgCO_2$/m) into ranges from 0.0 to 1.0. The parameters defining each function are shown in Table 7.7. In particular, the parameters of each function were defined based on other studies De La Fuente et al. (2019).

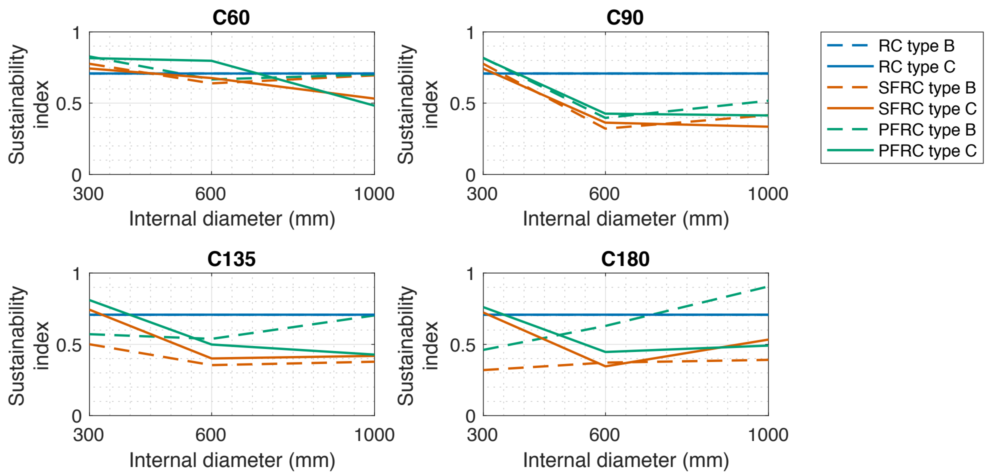

Figure 7.13. Global sustainability indexes of each alternative.

Table 7.7. Constitutive parameters of the value functions

	Indicator	X_{max}	X_{min}	C	K	P
R_1 **Economic**	I_1 Production costs I_2 Production time	1.25	0.75	2.00	700	3.00
R_2 **Environmental**	I_3 CO_{2-eq} emissions I_4 Non-renewables I_5 Energy	1.25	0.50	0.25	0.50	1.00
	I_6 Recyclability	1.25	0.75	0.50	6.00	3.10
R_3 **Social**	I_7 ORI	3.40	0.00	1.00	0.00	1.00
	I_8 Innovation	1.50	0.50	1.00	0.00	1.00

Indicator magnitudes for the alternatives were expressed relative to those for RCPs, taken as a reference, except for indicators I_6 and I_8, which were measured by attributes. The following criteria were assumed for defining the value functions constitutive parameters:

- For both production costs (I_1) and time (I_2), the market competitiveness was introduced by considering that the reference RCPs present a satisfaction of 0.75, which is high and reflects the existing level of optimisation achieved over time. Alternatives to traditional steel cage reinforcement would lead to the maximum satisfaction (1.0) for both indicators if a reduction of 25% of the corresponding magnitude is achieved; on the contrary, the minimum satisfaction (0.0) would be reached for an increase of 25% with respect to the reference values. The transition is simulated with an S-shaped function presenting remarkable sensitivity to increasing costs and time to further emphasise this competitiveness.
- The same value function was fixed for CO_{2-eq} emissions (I_3) and both non-renewal (I_4) and energy resources consumption (I_5) indicators. In an attempt to promote environmentally friendly practices, the 0.50 value was established for RCPs, while maximum and minimum satisfaction can be achieved by decreasing and increasing the reference values 50% and 25% respectively, using a convex function.
- A value of 0.5 was set as the reference value for RCPs for the satisfaction function of recyclability (I_6) to support alternatives with higher values for the recyclability attributes. For this indicator, the maximum value can be achieved by having indicators that are more than 25% of the refer-

ence value, whereas the minimum value is obtained when the indicator decreases 25% from the reference value. This is achieved through an increasing S-shaped value function.

- The satisfaction function for the occupational risks during construction indicator (I_7) was defined as decreasing linear so that the maximum satisfaction is obtained for a null ORI, and a value of 0.6 is obtained for the maximum ORI.
- For the satisfaction function of the indicator innovation (I_8), it was considered that the reference value for satisfaction was represented by a satisfaction of 0.5 for the RCPs, whereas the maximum or minimum values can be attained by increasing 50% or decreasing 50%, respectively, using an increasing linear function. Innovations in concrete pipe reinforcement could include enhancements in the welding process, the use of thermoplastic bendable rebars, and other systems that are arriving on the market.

7.4.5. Sensitivity analysis

The approach taken in the previous section was deterministic. This means that the results and corresponding discussion disregarded input data uncertainties (e.g. cost of the materials, amount of CO_2 emissions and embodied energy, weights, among others). However, the variability should be included to quantify the robustness of the results and the range of validity for the conclusions. The Monte Carlo method is used for this purpose.

This study considers two types of uncertainty linked to the model. The first corresponds to possible uncertainties in the weighting system. The second one corresponds to uncertainties linked to indicator quantification.

7.4.5.1. Uncertainties in the weighting system

The uncertainties in the weighting system were introduced at the requirements level by assuming a variation of a $\pm$10 % of each weight deterministic magnitude. The uncertainties were modelled using beta PERT distributions. One aspect to consider when introducing uncertainties in the weights is that, even with uncertainties, the weighting system of each level of the tree needs to add up to 100%. To take this aspect into account, the weights were normalised in each iteration of the Monte Carlo simulation.

The results of this probabilistic analysis are shown in Figure 7.14. The diagram presents the cumulative distributions of the sustainability indexes obtained for each alternative in 12 different plots. In this sense, the results make it possible to confirm that the ordering is maintained for almost all the alternatives, proving that the model is robust and dependencies not heavily dependent on the weighting system. In other words, the ordering and sustainability indexes derived from the deterministic analysis can be representative of a wide range of stakeholders' preferences (e.g. from pipe producer and public investor perspectives, whose interest and expectancies might differ).

7.4.5.2. Uncertainties in the data

As for the uncertainties in the data, it was considered that the highest uncertainties came from the costs of the three reinforcement types, corresponding to indicator I_1. Therefore, in this study uncertainties have only been introduced in the quantification of this indicator. The variations considered in this indicator for each of the alternatives is 5%, 15% and 20% for the steel bars, the steel fibres and the plastic fibres, respectively. These uncertainty levels reflect the variability on the production costs and the competitiveness for each product (higher for the fibres, and particularly for synthetic fibres).

The sensitivity analysis results are presented in Figure 7.15. In this case, the ordering is remarkably sensitive to the cost variability of the reinforcing material and the results that were presented before cannot be ensured in all cases within 90% confidence intervals. PFRCPs of $D_i = 300\ mm$ and 600 mm

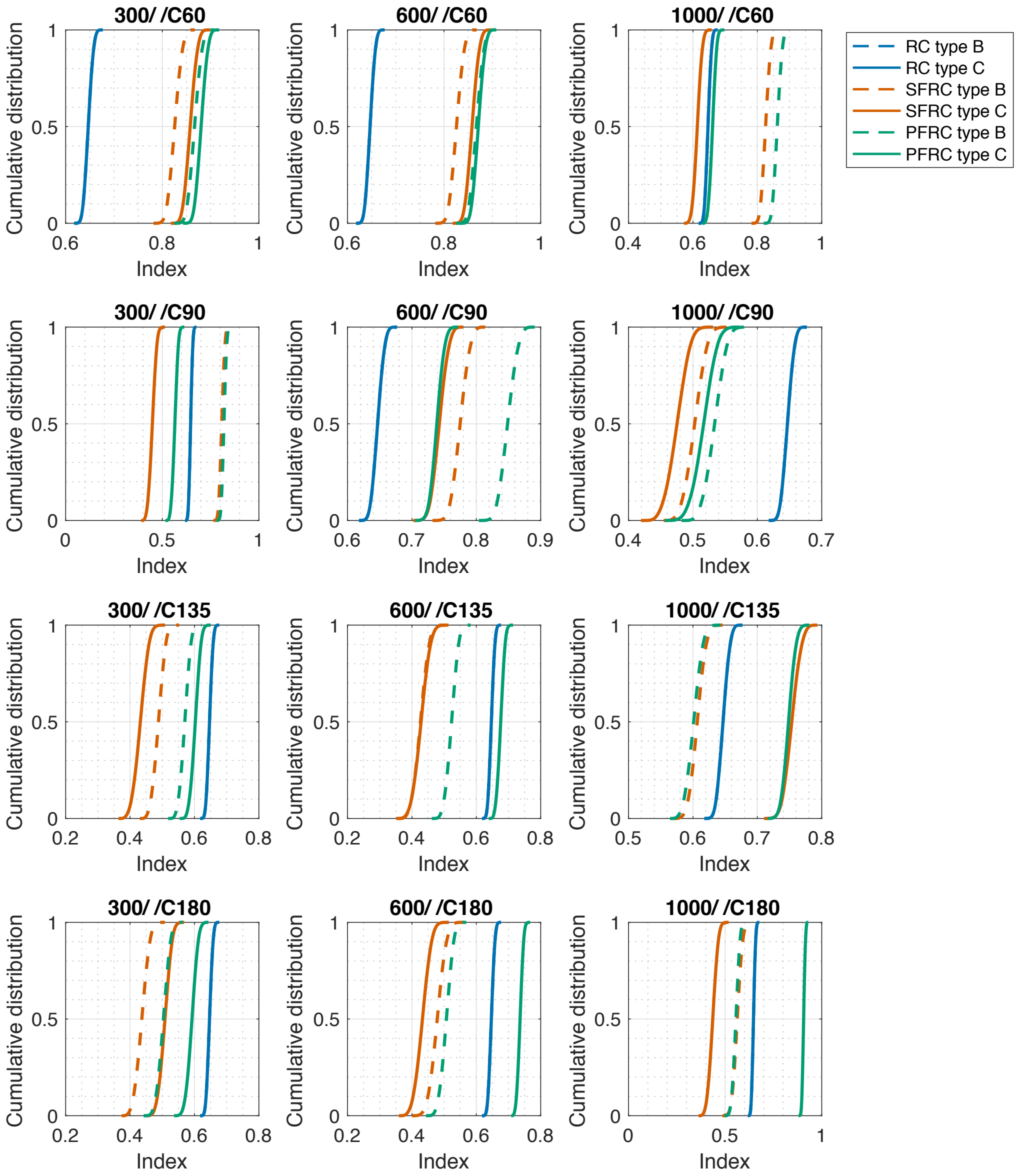

Figure 7.14. Cumulative distributions corresponding to each alternative for the probabilistic scenario with uncertainties in the weighting system.

and resistance class C60 perform better than RCPs. Besides, PFRCPs with wall type C, $D_i = 1000\ mm$ and resistance class C180 is also more sustainable than the other alternatives. RCPs with $D_i = 300\ mm$ and resistance classes C135 and C180 as well as with $D_i = 1000\ mm$ and resistance class C90 perform better than the other alternatives. In the remaining cases, sufficient robustness is lacking to draw any conclusions on a specific ranking between FRCPs and RCPs.

7.4.6. Conclusions

This case study proposes a methodology to assess the sustainability performance of CPs. The method is based on the use of MIVES, which allows alternatives to be compared and ranked based on sustainability. In particular, the model being developed is built upon three aspects: economy, environment and society. For each aspect, several criteria and indicators have been defined within experts' seminars to be able to evaluate the sustainability quantitatively.

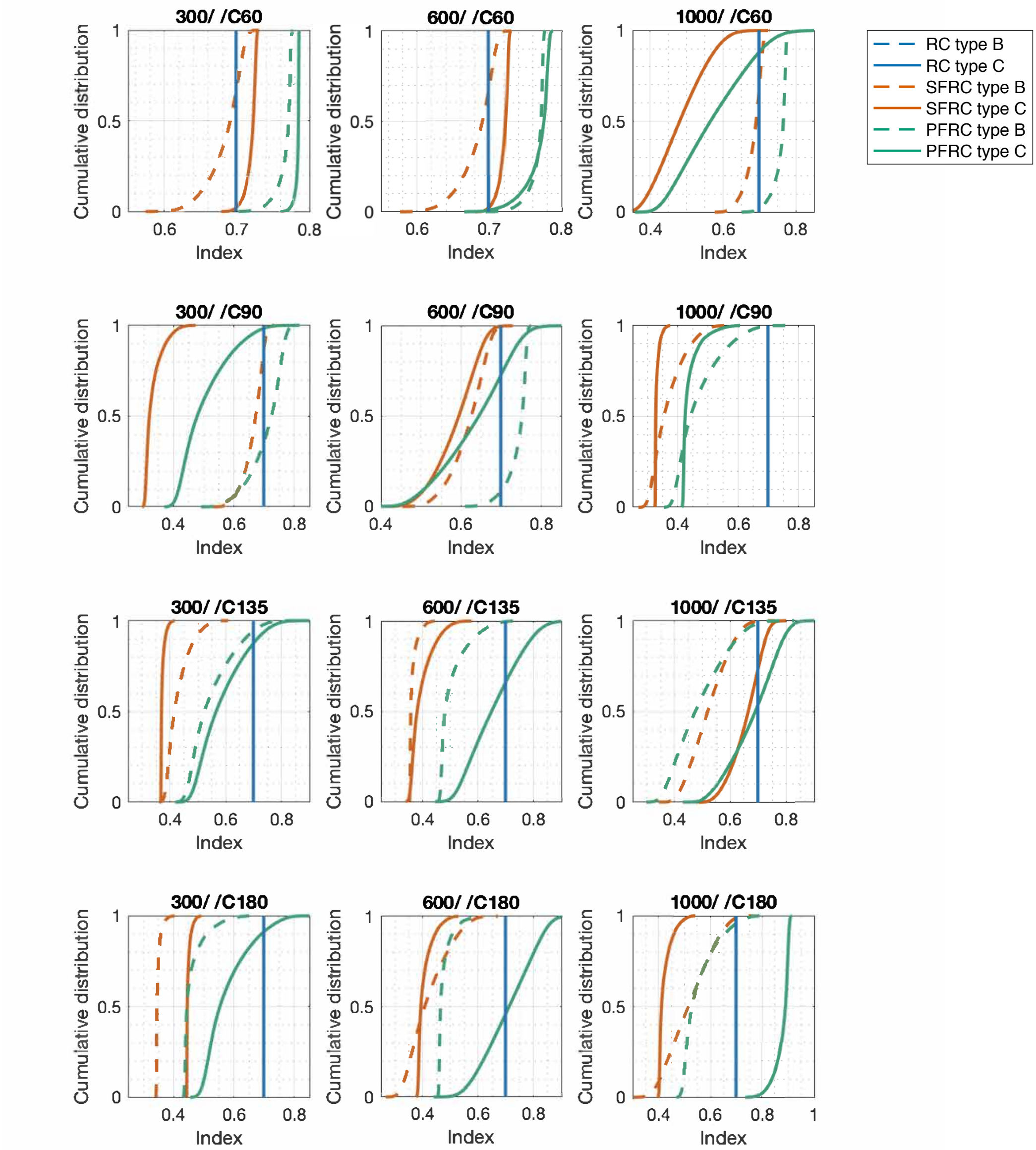

Figure 7.15. Cumulative distributions corresponding to each alternative for the probabilistic scenario with uncertainties in the data.

The model has been applied to a case study of reinforced concrete pipes. In particular, the alternatives considered had four main variables: the type of reinforcement (steel bars, steel fibres and synthetic fibres), the diameter (300, 600 and 900 mm), the thickness (type B or C according to UNE-EN 1916:2008 EN 1916:2008 (2008)) and the resistance class (C60, C90, C135 or C180). In total, 72 alternatives were analysed. The following conclusions can be drawn:

- Economically, FRCPs were demonstrated to be the most favourable alternatives to RCPs for lower diameters and resistance classes.
- Environmentally, PFRCPs are the most favourable. Besides, SFRCPs perform better than RCPs for low diameters and strength classes. On the one hand, SFRCPs are less advantageous in terms of recyclability with respect to PFRCPs and RCPs.
- Socially, FRCPs achieve better results than RCPs since production risks are lower.
- In terms of global sustainability, the results show that PFRCPs are more sustainable than RCPs

for $D_i = 300\ mm$, irrespective of the resistance class. However, overall, traditional alternatives (RCPs) are shown to perform slightly better as the diameter and the strength class increase.

- The sensitivity analysis on the weights showed that the model is robust under variations of the weighting system since the ordering remained unaltered for $\pm$10% variations of the weight magnitudes. On the contrary, the sensitivity analysis performed on the cost of materials led to higher variations from the deterministic scenario. In particular, 32% of the cases do not fall within a 90% confidence interval of the results. The fact that the relative ordering between alternatives is not maintained when costs vary highlights the importance of costs in the context of the decision-making process.

The decision-making model proposed herein, and the results obtained might be of interest to private and public stakeholders. Likewise, the model and its components can be adapted and calibrated to preferences and situations other than considered by the experts involved in the seminars.

Future research could move in two directions. First of all, pipes and most structural elements are designed by following specific regulations. However, certain solutions that are more innovative and better in terms of sustainability may not be considered in such regulations, which jeopardises the deployment of these technologies, and therefore the advancement towards more sustainable solutions. Hence, future research could focus on examining how legislations influence the design and construction of more sustainable structures. It needs to be noted that legislations are not the only barriers that may exist; other factors could also be slowing down the construction of more sustainable structures, such as society's resistance to changes.

Secondly, next studies could also focus on improving the MIVES methodology by examining how the perspectives of different stakeholders can be integrated into the model (multi-actor approach). Research in this area of study is still scarce, but considering multiple opinions is essential for a wider acceptance of decisions.

7.5. Summary

In this chapter, two different models for the sustainability analysis of infrastructure elements were developed using a multi-criteria decision-making method, MIVES.

The use of these tools can be a positive strategy in civil engineering courses where students are required to gain not only the competencies typical of engineering but also other aspects related, for instance, to social impacts. Drawing from the multi-attribute utility theory allows taking a holistic perspective to civil engineering problems by building an integrated value model to approach multi-criteria decision-making.

Specifically, the first application presented in this chapter was oriented explicitly to beams and girders, and it was applied to assess the sustainability of different materials and configurations for the structural element of roofs of sports halls. The second application focused on pipes, and evaluated the sustainability analysis of different reinforcement and geometric configuartions of concrete pipes.

8

Conclusions

8.1. General conclusions

In the last decade, the potential contribution that the social sciences and humanities can make on STEM fields has been increasingly acknowledged. STEM and the social sciences and humanities coexist and interact in several different ways that can enrich both academic research and professional practice. Even though some STEM fields have already made significant progress towards the integration of different domains within social sciences and humanities, other fields are still in their initial stages in terms of such consolidation.

In particular, the field of civil engineering still needs to advance towards such an interdisciplinary approach. This need arises from the fact that current societal challenges related to the field of civil engineering lie less in the development and application of sophisticated technologies, and more in their adequacy in terms of economic, environmental and social sustainability. Hence, incorporating social sciences and humanities as a pillar in the education of civil engineers is essential.

In this context, the primary objective of this dissertation was to fill the gap in terms of thinking processes, challenges, and opportunities related to the inclusion of social issues in civil engineering, by understanding better the potential contributions from relevant areas of the Social Sciences and Humanities in Civil Engineering and proposing recommendations accordingly.

The following sections present the general conclusions obtained for each of the specific objectives defined in Chapter 1. Then, the main contributions of the dissertation are outlined. Finally, some suggestions for future research and experimental campaigns are indicated given the space that there still exists for future studies in the subject treated in the thesis.

8.2. Conclusions regarding the specific objectives

The conclusions concerning each of the three specific objectives that were initially defined are summarised in what follows.

8.2.1. State-of-art of the relationship between civil engineering and the social sciences and humanities

The first specific objective set in this thesis was to compile comprehensive state-of-the-art information concerning the intersection between civil engineering and the social sciences and humanities. This was done through two main research lines. On the one hand, a conceptual framework was built as an approach to better understand the social dimensions in civil engineering. On the other hand, the status of civil engineering education was examined in a global setting, including how social issues are being integrated and the curricula and the conceptual and legislative aspects framing it.

8.2.1.1. Conceptual framework

The conceptual framework of the thesis was based on an extensive literature review of the literature in the intersection between the social sciences and humanities and civil engineering fields. For the framework, a taxonomy for both disciplines was established. This taxonomy included six fields of civil engineering, and twelve fields of the social sciences and humanities.

This allowed to describe both qualitatively and quantitatively the relationships between the scientific fields. Regarding how the relationships have been studied, it needs to be mentioned that governance, justice and vulnerability have been more widely studied in relation to civil engineering. In addition to this, the civil engineering subdiscipline where social topics have been more studied is transport. Additionally, when it comes to education, much of the research done until the present in the intersection between social sciences and humanities and civil engineering has focused mainly on the inclusion of concepts related to sustainable development in curricula and lifelong learning programs.

The results of the literature review carried out showed that the relationship between civil engineering and the social sciences and humanities is dual, heterogeneous and dynamic. First, the duality is given by the fact that infrastructures both shape and are shaped by social processes; secondly, it is heterogeneous because the strength of the relationship is not the same in all the intersection points; thirdly, it is dynamic because it changes affected by factors such as time.

Besides, it was found that the relationship between the two fields can be represented three-dimensionally by considering the externalities that characterise the specific intersections between subfields. These factors are: the stakeholder from whose point of view the relationship is analysed (user, local community, society, worker, etc.); time, which is usually defined through the different stages of the lifecycle of the infrastructure (design and planning, construction, operation and maintenance or decommission); and other possible externalities.

8.2.1.2. Worldwide status

Regarding the worldwide status of the integration of social sciences and humanities in civil engineering curricula, two main conclusions were extracted. On the one hand, knowledge at least up to a certain level on social sciences and humanities is considered relevant for civil engineers, as shown by the targets set out by professional institutions of civil engineers, which emphasise the importance of social issues in professional practice. In spite of this, only a minority of civil engineering schools have included social aspects in their curricula. Moreover, there is no common agreement among civil engineering curricula regarding the characteristics that this kind of subjects should have in terms of the proportion of credits, obligatoriness, the academic year in which these subjects are taught, and eligibility of the subject.

As for the specific social content that is included in the civil engineering programmes, it was found that the range of social sciences and humanities areas that are incorporated by different faculties is very wide. In extreme cases, students have the possibility of choosing any course from one or several social sciences and humanities faculties within the same university. Such an approach has the advantage that students can choose according to their interests and can obtain in-depth knowledge of certain social sciences and humanities subjects. Nonetheless, not contextualising the subject in the frame of civil engineering can make it difficult for students to comprehend how such technical social sciences and humanities knowledge can be applied in the context of civil engineering. This aspect was also supported by the results of the interviews, as will be explained after.

The diversity in the methods in which social aspects are introduced, and the contents that are included can be seen as the result of a lack of consensus among accrediting bodies, which have not yet introduced social sciences and humanities subjects as a specific requirement in their criteria, as well as a lack of a specific social sciences and humanities body of knowledge for civil engineers. The latter problem may be a consequence of the area of study still being in its infancy and of a dearth of discussions around this topic, both in academia and practice.

On the other hand, several barriers were found regarding the introduction of social sciences and humanities content in civil engineering programmes: the resistance to change from individuals or groups, external influences on the curricula, the lack of clear guidelines or study cases on the methodology and the contents that should be incorporated, and the diversity in the conceptualisation of the social side of civil engineering.

8.2.2. Perceptions towards the relationship between civil engineering and the social sciences and humanities

The second specific objective that was defined in the present thesis was to analyse what the perceptions among civil engineering academia are towards the relationship between the social sciences and humanities and civil engineering. For this, two different aspects were analysed. First, the perceptions at a national and global scale towards the relationship between civil engineering and the social sciences and humanities was investigated from the perspectives of professors. Besides, the perspectives of students and practitioners was analysed for the national case. Second, these perceptions were compared across groups (professors, students and practitioners).

8.2.2.1. Perceptions by professors at a national and global scales

It was found that some of the factors affecting the process of integrating relevant social content in civil engineering programmes were similar in different countries, while a few of them were particular for different contexts (in which case they were analysed in more detail only for the case of Spain). These factors were grouped into four elements, namely ability, preparedness, willingness and propitiousness. These elements help to explain what hinders the integration of relevant content from the social sciences and humanities in civil engineering educational programmes.

- Ability refers to the ability of making changes by different actors in the academic environment. For instance, regulations or certain rules may make it more difficult to integrate new concepts in programs or specific subjects. Another example would be that one of professors that are not the coordinators of a subject and do not have the capability of integrating new concepts.
- Preparedness refers to the state of being prepared for making the necessary changes addressed in this study. A related example would be the lack of training that some professors felt and that hindered their capability of integrating social issues in their subjects.
- Willingness refers to the fact that individuals may or may not be willing to introduce or adopt changes in their academic activities even when they are able, and trained for it.
- Propitiousness refers to the issue of whether the environment is favourable or not to changes. It could be that the (academic) environment is not suitable or advantageous for this specific purpose.

> Also, the global situation may be more or less favourable for integrating social issues. In the present case, this was reflected in the state of the civil engineering profession and education.

Additionally, it was seen that there are several factors that are not directly related to social contents in civil engineering education have, such as the legislative structures that govern university systems, the system of "incentives" given to professors for carrying out specific tasks such as teaching innovation activities, or the personal relationships existing between professors, and between professors and students.

Regarding the specificities of the Spanish civil engineering education context, three main factors were found that are particular for such context. First, there is the situation of the civil engineering profession, highly influenced by the 2008 crisis, but also by the way in which it was originally conceived and the elitist role that civil engineers had in society during the 20th century. Second, there is the university system and the ways in which faculty members establish themselves in the schools. This includes the selection procedures, and the types of positions, including both tenured and non-tenure positions. And, third, it is important to consider the characteristics of the whole educational system, including pre-university studies, and undergraduate and postgraduate ones.

8.2.2.2. Comparison of perceptions between professors, students and practitioners

Three main areas were found to be relevant when comparing perceptions between professors, students and practitioners within the framework of this thesis: the conceptualisation of what the social dimension of civil engineering is, the perceptions towards education, and the impression towards the necessary social competencies for civil engineers.

As for the perceptions on what the social within civil engineering is, it was found that the latent variable explaining the perceived societal contribution is similar to the one explaining the perception of the contributions of sciences such as chemistry or biology. Nonetheless, these results were slightly different when analysed through a gender perspective.

Concerning the perceptions towards education, it was seen that there are discrepancies between what professors believe they teach and what they think should be taught, as well as with what students perceive they are being taught. Nonetheless, among students, it was seen that the perceptions by new students of what social contents they should be taught matches well with what current students think they have been taught.

Thirdly, with regard to the perceptions towards the social competencies, these were analysed in two different groups; namely, technical and transversal social skills. The results showed several mismatches between the groups analysed towards these competencies, mainly between practitioners and academia. Besides, these differences are more relevant in the case of social technical competencies than transversal competencies.

8.2.3. Integration of social sciences and humanities in civil engineering programmes

The last specific objective of this work was to propose specific ways in which social dimensions can be more effectively integrated into different subjects of civil engineering programmes. This was done through the development of two case studies.

The first case implemented a decision-making model to evaluate the sustainability of structural elements for roofs. In particular, seven alternatives were considered, namely a flat steel truss, a sloped steel truss, a prestressed concrete girder, a lightened prestressed concrete girder, a concrete truss, a timber truss and a timber girder. Results showed that, economically, the best solution is the concrete truss. Nonetheless, socially all the alternatives yield very similar results, the steel alternatives being slightly better. As for the global sustainability index, the differences of the index's value of the timber and reinforced concrete trusses and of the timber and prestressed concrete girders were not found to be significant.

The second case used the same decision-making method, MIVES, to assess the sustainability of different reinforcement materials for concrete pipes. In particular, the alternatives considered had four main variables: the type of reinforcement (steel bars, steel fibres and synthetic fibres), the diameter, the thickness and the resistance class.

In addition to the conclusions directly related to the sustainability indexes obtained, the analyses conducted allowed reflecting that case studies where sustainability is used as a framework can be useful to develop certain social competencies in class. In particular, the two cases could tackle two of the competencies typical of advanced civil engineering courses[1], as well as some of the transversal competencies that are common in engineering courses, such as sustainability and social commitment, effective oral and written communication, or teamwork.

8.3. Major contributions

The major contributions of this work might be summarised as follows:

- In ***Chapter 3***, the relationship between social sciences and humanities and civil engineering was examined from a holistic perspective and a conceptual framework was proposed. For this, define subfields of civil engineering and of social sciences and humanities were defined a taxonomy for each of them was established. The review allowed establishing a framework that described both qualitatively and quantitatively the relationships between the scientific fields.
  This study can be considered as being the first step towards a better understanding of the connections between two fields that are frequently treated as independent, in spite of the fact that they are actually dependent one on the other. An integrated and interdisciplinary approach to the intersection between civil engineering and social sciences and humanities is fundamental, both for academicians and for practitioners.
- ***Chapter 4*** analysed how social sciences and humanities are currently perceived and implemented in civil engineering HE programmes worldwide. For the analysis, a triangular approach has been taken where information from interviews and bibliographic research was combined with archival records to better understand the current role of social sciences and humanities in universities and to propose methodologies through which social topics can be introduced in formal HE programmes. The analysis performed also helped to reinforce the need to consolidate a civil engineering body of knowledge that is comprised both of technological and social technical knowledge.
- The analysis presented in ***Chapter 5*** allowed to analyse in detail a specific case within the context of the previous chapter. In particular, the case of civil engineering education in Spain was examined, using both interview and survey data.
  To the best of the doctoral candidate's knowledge, no such specific study had yet been carried out on the status of civil engineering education in Spanish civil engineering schools, focusing on implementing changes in the programmes and, more particularly, on introducing social issues in the syllabus.
- In ***Chapter 6***, main issues arising from the previous chapters were analysed in more detail. First,

[1] These are (1) Knowledge of all types of structures and their materials, and ability to design, design, execute and maintain civil works structures and buildings; and (2) knowledge and ability for structural analysis through the application of methods and programs of design and advanced calculation of structures, from the knowledge and understanding of the applications and their application to the structural typologies of civil engineering. Ability to perform structural integrity assessments.

the way in which the social contribution of civil engineering is perceived was analysed. This is particularly relevant to understand better how different stakeholders perceive the importance of social sciences and humanities to civil engineering. Second, the ways in which civil engineering students perceive social content in their programme was examined to contrast it with professors' perceptions. And, third, a study of social competencies was carried out. This is specifically relevant in a context where researchers have pointed at the importance of analysing what competencies are needed for engineers in the current world.
- ***Chapter 7*** drew from the gaps detected in the previous chapters to propose specific ways to integrate social aspects in civil engineering. Since it was found that it is common that professors find it complex to integrate social issues in structural analysis and material sciences courses, two case studies were developed where the sustainability framework is used as a means to produce a multi-criteria decision-making model.

8.4. Limitations and suggestions for future work

The result of this thesis aims to cause an impact on how relevant contents from the social sciences and humanities are integrated in the education and professional practice of civil engineers. However, given the breadth of the topic examined, there are various avenues for future research related to the results of this dissertation that would benefit from further investigation. They can be grouped into three main topics: conceptualisation, education, and practice. They are described next.

8.4.1. Conceptualisation

The analysis of how the concept of the "social" is perceived was done qualitatively among professors in three different Spanish civil engineering schools, and quantitatively among students, researchers, professors and practitioners in the field of civil engineering. This study could be extended in order to understand better the etymology of the concept. Advances in education and practice would greatly benefit from such an understanding.

In particular, the extension of the study could be done in three different lines:

- Examining how the concept is perceived in other geographical locations.
- Studying how this conceptualisation differs in other engineering fields.
- Analysing how non-engineers perceive the social in civil engineering.

8.4.2. Education

The qualitative study that was performed in the dissertation allowed understanding what the factors that affect the incorporation of social issues in civil engineering subjects and programmes are. Nonetheless, the study was focused on the opinions by professors. This allowed understanding the practical and institutional aspects related to such incorporation. Future studies could analyse the same issue but from a student perspective, which would allow learning what are the specific drivers, barriers, and perceptions that this stakeholder group has towards the social sciences and humanities.

Besides, in this interviews-based study, four elements were detected that were affecting the adequate integration of these elements. It would be appropriate to extend the analysis by finding specific ways in which each of these elements can be tackled.

Finally, the question of the equilibrium between breadth and depth needs to be further analysed. In this dissertation, this issue was mainly discussed on the basis of the responses of professors and in the context of integrating social aspects in engineering education. This question would greatly benefit from interviews with practitioners that would give their perspective about balancing the two dimensions.

8.4.3. Practice

This dissertation proposes specific methods through which social issues can be integrated in civil engineering programmes at universities. Even though training future engineers in this area is essential for the professional practice, it would also be important to examine specific ways in which content from the social sciences and humanities can be integrated in projects by civil engineers.

Ultimately, and given the current world situation, these aspects can be incorporated together with the sustainability framework. The “social” is, eventually, one more aspect apart from environmental and economic concerns in a project. Therefore, project management processes that integrate a sustainability objective should be analysed from a conceptual perspective, and real projects where the social has been relevant could be investigated in depth.

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A

Additional information on the methods

This appendix contains supplementary details on the methodology followed in the thesis. The universities analysed as part of the review of documents is presented (Section A.1), and then further details are provided on item analysis, which is one of the bases for the analysis of the surveys (Section A.2).

A.1. Secondary documents analysis

Table A.1 shows the list of all the universities that have been analysed for the comparison of civil engineering syllabuses. The table shows the country in which they are located and their position according to the QS ranking.

Table A.1. Universities analysed, together with their country and position in the QS ranking

Position	University	Country
1	MIT	USA
2	National University of Singapore	Singapore
3	University of California, Berkeley	USA
4	Delft University of Technology	Netherlands
5	University of Cambridge	UK
6	Imperial College of London	UK
7	Politecnico di Milano	Italy
8	ETH Zurich	Switzerland
9	Tsinghua University	China
10	Nanyang Technological University (Singapore)	Singapore
11	Ecole Polytechnique Federale de Lausanne	Switzerland
12	UNSW Sydney	Australia
13	Stanford University	USA
14	Georgia Institute of Technology	USA
15	Hong Kong Polytechnic University	Hong Kong
16	University of Oxford	UK
17	Hong Kong University of Science and Technology	Hong Kong
18	University of Hong Kong	Hong Kong
19	University of Tokyo	Japan

Table A.1 continued from previous page

20	University of Sydney	Australia
21	University of Illinois at Urban-Champaign	USA
22	University of Melbourne	Australia
23	Universitat Politècnica de Catalunya	Spain
24	Kyoto University	Japan
25	Politecnico di Torino	Italy
26	University of Texas Austin	USA
27	Shanghai Jiao Tong University	China
28	KAIST	South Korea
29	Purdue University	USA
30	Monash University	Australia
31	Seoul National University	South Korea
32	University of British Columbia	Canada
33	University of Western Australia	Australia
34	University of Michigan	USA
35	University of Toronto	Canada
36	University of Queensland	Australia
37	National Taiwan University	Taiwan
38	Pontificia Universidad Católica de Chile	Chile
39	University of Auckland	New Zealand
40	Tongji University	China
41	University of Manchester	UK
42	Tokyo Institute of Technology	Japan
43	KTH Royal Institute of Technology	Sweden
44	University of Sheffield	UK
45	Universidad Politécnica de Madrid	Spain
46	Universidade de Sao Paulo	Brazil
47	Texas A&M University	USA
48	Hanyang University	South Korea
49	National Technical University of Athens	Greece
50	Technical University of Denmark	Denmark
51	Universidad Nacional Autónoma de México (UNAM)	Mexico
52	California Institute of Technology (Caltech)	USA
53	Carnegie Mellon University	USA
54	Chalmers University of Technology	Sweden
55	City University of Hong Kong	Hong Kong
56	Columbia University	USA
57	Cornell University	USA
58	Curtin University	Australia
59	Ecole des Ponts ParisTech	France
60	Indian Institute of Technology Bombay (IITB)	India
61	Indian Institute of Technology Delhi (IITD)	India
62	KU Leuven	Belgium
63	KIT, Karlsruhe Institute of Technology	Germany
64	Korea University	South Korea
65	McGill University	Canada
66	Northwestern University	USA
67	Norwegian University of Science And Technology	Norway
68	Université PSL	France

Table A.1 continued from previous page

69	Peking University	China
70	Pennsylvania State University	USA
71	Princeton University	USA
72	Queensland University of Technology (QUT)	Australia
73	RWTH Aachen University	Germany
74	RMIT University	Australia
75	Sapienza University of Rome	Italy
76	Technical University of Munich	Germany
77	The University of Adelaide	Australia
78	University of Nottingham	UK
79	UCL	UK
80	Universitat Politècnica de València	Spain
81	University of Naples - Federico II	Italy
82	Universiti Malaya (UM)	Malaysia
83	Universiti Teknologi Malaysia	Malaysia
84	University of Birmingham	UK
85	University of Bristol	UK
86	University of California, Davis	USA
87	University of California, Los Angeles (UCLA)	USA
88	University of Canterbury	New Zealand
89	The University of Edinburgh	UK
90	University of Leeds	UK
91	University of Lisbon	Portugal
92	University of Porto	Portugal
93	University of Southampton	UK
94	University of Technology Sydney	Australia
95	University of Waterloo	Canada
96	University of Wollongong	Australia
97	Vilnius Gediminas Technical University	Lithuania
98	Virginia Polytechnic Institute and State University	USA
99	Yonsei University	South Korea
100	Zhejiang University	China

A.2. Item Analysis

A.2.1. Overview of item analysis

As it was mentioned in 2, analysis of the surveys was done through various techniques, including item analysis. Item analysis provides a way of measuring overall performance, test quality, and individual responses to survey questions. As it was mentioned above, some of the analysis methods used are based on item analysis. This is why it is described here. However, note that this not represents the sole analytical framework applied.

Item analysis is commonly used in the field of education, and it is considered that there are two different approaches to analysing data: Classical Test Theory (CTT) and Item Response Theory (IRT). Both theories allow predicting the outcomes of survey questions and provide measures of validity and reliability.

These two theories, CTT and IRT, are compared in Table A.2 and are described next in more detail.

Table A.2. Comparison between CTT and IRT (adapted from Eleje et al. 2018)

	CTT	IRT
Model	Linear	Nonlinear
Unit of analysis	The test is the unit of analysis.	The item is the unit of analysis.
Item-ability relationship	Not specified	Through item characteristics functions
Number of items for reliability	More items make the measure more reliable	Measures with fewer items may be more reliable
Comparison	Scores from different measures can only be compared when the test measures are parallel	Responses from different measures can be compared as long as they measure the same latent trait
Item properties	Depend on the representativity of the sample	Do not depend on the representativity of the sample
Position on the latent trait continuum	It is obtained from comparing the test score with scores of the reference group	It is derived by comparing the distance between items on the ability scale
Response categories	All items on the measure must have the same response categories	Different items on a measure can have different response categories

On the one hand, CTT is sometimes regarded as the "true score theory", as it assumes that the responses of examinees to a test are only affected by their ability. Other potential sources of variation in tests, such as external or internal conditions, are assumed to be constant or to have an effect that is random by nature (van der Linden and Hambleton, 2010).

The central model of CTT can be illustrated by the following formula (Novick, 1966, Spearman, 1904):

$$OS = TS + ES \tag{A.1}$$

Where *OS* represents the observed test scores, and it is composed by a true score (*TS*) and an error score (*ES*), where *TS* and *ES* are independent.

The focus of CTT methods of analysis is on the following items: total test score, frequency of correct responses, frequency of responses, and reliability of the test and item-total correlation. Even though these statistics are widely used, they have one main limitation: they depend on the sample scrutiny and thus all the statistics that describe items and questions are sample dependent (Hambleton, 2000). Even though this may not be relevant if successive samples are found to be representative, this still needs to be confirmed. Various authors have proposed strategies to overcome this limitation.

On the other hand, IRT is a theory that was first proposed in the field of psychometrics to assess ability. In the literature, it is also referred to as latent trait theory or item characteristic curve theory. It is commonly used in education, where tests, questionnaires, and other instruments need to be calibrated and evaluated, and where subjects are scored depending on certain latent traits.

The foundation of IRT is a mathematical model that is used to predict the probability of success of a person on an item, depending on the ability of the person and the item's difficulty. Hence, the model relates the ability or trait measured by the instrument (represented with θ) and the response to an item.

The response to the item can have two categories (for instance, yes and no), in which case dichotomous models are used, or more than two categories (for instance, a Likert scale), and then polytomous models are used.

Apart from the dichotomous/polytomous differentiation, IRT models can also be classified into unidimensional and multidimensional models. The former are used when the focus is on the measurement of one single latent trait, whereas the latter are advised for the measurement of more than one latent construct.

Each model can also be characterised by the number of parameters that define their mathematical expression, from one to four, which gives rise to different types of models referred to as 1PL, 2PL, 3PL, and 4PL.

The assumptions that IRT makes are the following ones:

1. Monotonicity. This assumption indicates that the probability of a correct response increases when the trait level increases.
2. Unidimensionality. IRT models assume that there is only one dominant latent trait that influences the responses for each item.
3. Local independence. Responses given to one item are independent of the responses to another item, conditional on the latent trait.
4. Invariance. Item parameters of the model can be estimated from any position on the item response curve.

The key parameters of IRT models are the following ones:

- *Item discrimination*. It is denoted a, and it determines the rate at which the probability of endorsing a correct item changes given ability levels, but it can also be understood as to how well an item can differentiate between examinees at different trait levels.
- *Item location*. It is also referred to as item difficulty, and it is denoted b.
- *Guessing*. If the response to an item involves guessing, the guessing parameter may be included in the model. It is denoted c, and it describes the probability that a response to an item is due to guessing. Items with a guessing parameter greater than 0.35 are usually considered unacceptable. This guessing parameter is not frequently used because it is not always applicable.
- *Trait score*. The responses of individuals are used to calculate their trait score or ability (θ). This parameter estimates their position along the underlying trait measured.

As means of summarising the information above, Figure A.1 shows a scheme with the two theories, CTT and LTA, and the various models that make them up.

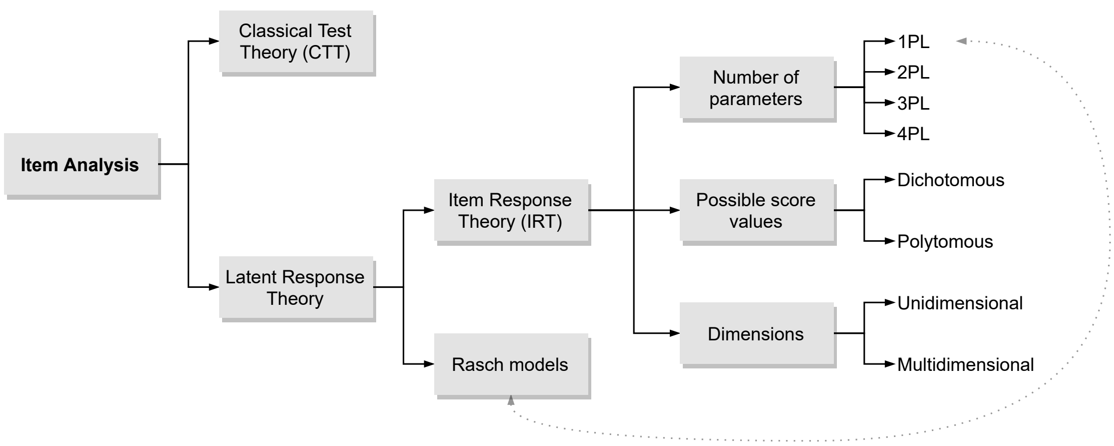

Figure A.1. Item analysis theories

A.2.2. Item Response Theory models

There exists a wide variety of IRT models that accommodate different measurement situations. Next, the different possible models will be described. In the present thesis, multidimensional models were not used. Therefore, only unidimensional models with dichotomous and polytomous scales will be presented.

A.2.2.1. Dichotomous models

First of all, starting with unidimensional dichotomous models, note that a dichotomous item is one where there are only two response categories (correct or incorrect). Hence, such models show the probability of a score of 1 (corresponding to correct response). This probability can be expressed as a function of θ:

$$P(x_{ip} = 1|z_p; \theta) \tag{A.2}$$

Where x_{ip} is the response of the pth subject to the ith item, z_p is the latent variable (for example, the latent ability to score high) and θ is a parameter describing this relationship. Given that the data is dichotomous, x_{ip} can only take two values.

There are three models that are typically used for dichotomous items: the three-parameter, two-parameter, and one-parameter logistic models. They are referred to as 3PL, 2PL and 1PL respectively. The three parameters that are used in these models are the discrimination index, or slope, a, the difficulty parameter, b, and the lower asymptote parameter, c, which provides the probability that an examinee with a low level of θ gets the item right.

The mathematical equation of the 3PL model is as follows:

$$P(x_j = 1|\theta_j, a_i, b_i, c_i) = c_i + (1 - c_i)\frac{e^{a_i(\theta_j - b_i)}}{(1 + e^{(a_i(\theta_j - b_i)}} \tag{A.3}$$

Where $P(\theta_j)$ represents the probability of correct response given θ and the item parameters a, b, c, for respondent j. The subscript i represents the item, i. The ranges for each parameter are $\theta_j \in (-\infty, \infty)$, $a_i \in (0, \infty)$, $b_i \in (-\infty, \infty)$, and $c_i \in [0, 1]$.

The 2PL model is a special case of the 3PL model in which the lower asymptote value, c, is fixed to 0. Hence, it can be written as:

$$P(x_j = 1|\theta_j, a_i, b_i) = \frac{e^{a_i(\theta_j - b_i)}}{(1 + e^{(a_i(\theta_j - b_i)}} \tag{A.4}$$

Finally, for the 1PL model, the additional assumption is that $a_i = 1$ for all items, yielding:

$$P(x_j = 1|\theta_j, b_i) = \frac{e^{(\theta_j - b_i)}}{(1 + e^{((\theta_j - b_i)}} \tag{A.5}$$

In some cases, a_i is substituted by 1.7 instead. The reasons for using this coefficient can be found in DeMars 2010.

The three models described above are the most common ones. The 4-parameter model, the 4PL, also exists even though it not as much used. It is represented through the following expression:

$$P(x_j = 1|\theta_j, a_i, b_i, c_i, d_i) = c_i + (d_i - c_i)\frac{e^{a_i(\theta_j - b_i)}}{(1 + e^{(a_i(\theta_j - b_i)}} \tag{A.6}$$

Where d is an upper asymptote parameter for the item response function.

A.2.2.2. Polytomous models

Apart from dichotomous models, several models have been proposed for the analysis of polytomous items in IRT. The case for polytomous data is similar to the dichotomous one, but now the subjects can answer in more than two categories. In this case, the relation that is examined is given by the following expression:

$$P(x_{ip} = k|z_p; \theta) \tag{A.7}$$

Polytomous models can be divided between those that can be used with items that have ordered categories (such as Likert-type items), and those that can be used with categorical items. Nonetheless, the present thesis only introduces those with ordered categories as they will be the ones needed for the study.

Several models have been proposed and used for polytomous items in which the categories of the items are ordered. Two models will be presented here: the Generalized Partial Credit (GPC) model (Samejima, 1969) and the Graded Response (GR) model (Muraki, 1992). It needs to be mentioned that when there are only two categories, the GPC and the GR models are equivalent to the 2PL model.

A.2.2.3. Rasch model

A special type of 1PL model is the Rasch model (Rasch 1960), which was independently developed. In fact, even though The Rasch model is considered to be one IRT model of 1 parameter (1PL), other researchers prefer viewing it as a different approach. The main differences between the Rasch model and the 1PL model is that Rasch constrains ai (the item discrimination) to 1, while the 1PL fits the data as much as possible and hence does not limit ai to 1.

The Rasch model can be expressed through the following formula:

$$P_{ij}(\theta_j, b_i) = \frac{e^{\theta_j - b_i}}{1 + e^{\theta_j - b_j}} \tag{A.8}$$

Where θ represents the ability, and b_i the difficulty parameter. Note that, as defined by Rasch, the latent trait was represented with the symbol β as the notation system is different. The Rasch model, as well as the 1PL model, has some desirable properties that the other two models do not have (DeMars 2010). For instance, the observed scores are a sufficient statistic for the latent trait, which means that all respondents with the same number of correct scores will have the same estimated latent trait.

The above-presented Rasch model can be extended to the polytomous case, in which α_i equals 1 for all items, and therefore the expression is the following one:

$$P(x_{ip} = k|z_p;\theta) = \frac{e^{\sum_{c=0}^{k}\left(z_p-\delta_{ic}\right)}}{\sum_{r=0)}^{K_i} e^{\sum_{c=0}^{r}\left(z_p-\delta_{ic}\right)}} \tag{A.9}$$

B

Survey

This appendix contains additional information on the survey carried out as part of the quantitative methodology for the thesis. The questions included in the questionnaires are presented (Section B.1), followed by the descriptive statistics of the responses to each question (Section B.2).

B.1. Survey questions

In this section, the questions included in the survey are presented. As it was explained in the main document, there were five main blocks of questions, which have been represented here using the following (uppercase) letters:

- **P**: Personal information
- **G**: General questions
- **S**: Specific questions
- **E**: Education questions
- **W**: Profession

The structure of the survey was complex, as different questions were asked to different groups and depending on their previous responses. When specific questions were only asked to certain groups, this has been represented using the following (lower case) letters:

- **s**: students (**ns**: new students, **us**: undergraduate students, **gs**: graduate students)
- **p**: professors
- **w**: practitioners

In the questions, the □ represents multiple-choice questions where respondents could choose more than one answer, whereas ○ represents multiple-choice questions with only one possible answer.

Thank you for your availability to answer this survey, which has been developed in the context of a PhD thesis at Universitat Politècnica de Catalunya.

The survey has been developed to understand the current perception in society with regard to civil and environmental engineering; besides, it will allow to analyse the application of sustainability criteria in the profession.

We deeply appreciate the time you will take to answer it.

This time is, approximately, of 12 minutes.

Confidentiality statement: all the provided information will be strictly confidential and will not be individually disclosed.

Personal information

Q1 Age

- ○ 21 years old or less
- ○ 22-25 years old
- ○ 26-29 years old
- ○ 30-34 years old
- ○ 35-39 years old
- ○ 40-44 years old
- ○ 45-54 years old
- ○ 55-64 years old
- ○ 65 years old or more

Q2 Nationality

▼ Dropdown menu with names of all countries

Q3 Current country of residence

▼ Dropdown menu with names of all countries

Q4 Gender

- ○ Female
- ○ Male
- ○ I don't identify myself with any of the options
- ○ I prefer not to answer

Q5 Highest level of education completed

- ○ Secondary school
- ○ Bachelor of Science
- ○ Master of Science
- ○ Doctorate
- ○ Others (please specify)

Q6–s,p Current occupation

- ○ Undergraduate student
- ○ Master's student
- ○ PhD student
- ○ Professor and/or researcher
- ○ Others (please specify)

Q7-s p Which one of the following options best describes your current academic field?

- ○ Environmental engineering
- ○ Structural and construction engineering
- ○ Transport and mobility
- ○ Marine sciences
- ○ Geotechnical engineering
- ○ Numerical methods in engineering
- ○ Seismic engineering and structural dynamics
- ○ Others (please specify)

Q8-s p How long have you been in your current occupation?

- ○ 1 year or less
- ○ 2 years
- ○ 3 years
- ○ 4 years
- ○ 5 years
- ○ 6 years or more

Q9-s p In which type of activities do you take part in outside of the academic environment?

- □ Cultural activities
- □ Sports and physical activities
- □ Creative activities
- □ Personal/spiritual development
- □ Community service or volunteering
- □ Professional training
- □ Learning courses
- □ I don't take part in any activity
- □ I prefer not to answer
- □ Others (please specify)

Q6–w Which of the following best describes the field in which you primarily work?

- ○ Civil and environmental engineering; design, construction and management of infrastructure
- ○ ICT services (Information and Communications Technology)
- ○ Industrial engineering and industrial processes
- ○ Architecture
- ○ Other engineering specialities
- ○ Scientific and technical services
- ○ Agriculture, forestry, fishing
- ○ Education, training
- ○ Entertainment, culture, sports
- ○ Healthcare services
- ○ Hospitality, tourism
- ○ Financial services, banking, insurance
- ○ Community and social services
- ○ Legislation and jurisdiction
- ○ Media, publishing
- ○ Security, cleaning, homework
- ○ Administration services
- ○ Manufacture
- ○ Government and public administration
- ○ Real state, renting
- ○ Sales
- ○ Others (please specify)

Q7–w What sector are you working in?

- ○ Public sector
- ○ Private sector
- ○ Other (please specify)

Q8–w What kind of tasks does your company carry out?

- ○ Infrastructure planning and design
- ○ Construction
- ○ Infrastructure management
- ○ Other (please specify)

Q9–w Which of the following best describes the field of your current occupation?

- ○ Transport infrastructure and mobility
- ○ Energy infrastructure
- ○ Urban planning
- ○ Environmental engineering
- ○ Hydraulic infrastructures and water management
- ○ Buildings
- ○ Other (please specify)

Q10–w What is your current position?

- ○ Technician, professional
- ○ Administration, human resources
- ○ Commercial
- ○ Researcher
- ○ Supervisor
- ○ Head of section
- ○ Area director
- ○ General director
- ○ Other (please specify)

Q11-w p In which type of activities do you take part in outside of the academic environment?

- ☐ Cultural activities
- ☐ Sports and physical activities
- ☐ Creative activities
- ☐ Personal/spiritual development
- ☐ Community service or volunteering
- ☐ Professional training
- ☐ Learning courses
- ☐ I don't take part in any activity
- ☐ I prefer not to answer
- ☐ Others (please specify)

General block

G1 In your opinion, what is the importance of the following scientific and technologic fields on social well-being?

	Not at all important	Not very important	Moderately important	Important	Very important
Civil engineering	○	○	○	○	○
History, literature, philosophy	○	○	○	○	○
Psychology, sociology	○	○	○	○	○
Arts	○	○	○	○	○
Economics, law, politics	○	○	○	○	○
Chemistry, biology	○	○	○	○	○
Agriculture, fishing	○	○	○	○	○
Education and pedagogy	○	○	○	○	○
Architecture	○	○	○	○	○
Maths, physics	○	○	○	○	○
Medicine	○	○	○	○	○

G2 When planning, designing and building a civil engineering project, how would you prioritise the following aspects?

- ☐ Environmental aspects
- ☐ Social aspects
- ☐ Economic aspects

G3 In the design stage of a civil engineering project, what is the relative importance, in your opinion, that the following factors should have?

- ☐ Reduction of emissions (such as CO_2 or NO_x)
- ☐ Correct and efficient management of the generated waste
- ☐ Adaptation to the social context (cultural, historic, etc.)
- ☐ Labor, materials and transportation costs
- ☐ Enhancement of the users' quality of life
- ☐ Economic profitability of the project

Specific block

S1 Please indicate what is the importance that the following types of infrastructure have on social well-being. Choose the most appropriate answer according to you.

	Not at all important	Not very important	Moderately important	Important	Very important
Transportation and mobility *Roads, bridges, railroad, etc.*	○	○	○	○	○
Energy *Generation, distribution, etc.*	○	○	○	○	○
Urban planning *Urbanism, architectural design, land use, etc.*	○	○	○	○	○
Environment *Pollution control, disposal of waste, etc.*	○	○	○	○	○
Water *Supply, distribution, sanitation, etc.*	○	○	○	○	○
Buildings *Housing, educational, etc.*	○	○	○	○	○

S2 Different social factors are listed below. Please indicate for which types of infrastructure it is most important to take them into account. Choose the most appropriate answer according to you. You can choose up to three options for each of the social aspects.

⁎ **S2.1 Cultural and historical context**

- ☐ Transportation
- ☐ Energy
- ☐ Environment
- ☐ Urban planning
- ☐ Water
- ☐ Buildings
- ☐ N/A

⁎ **S2.2 Human behaviour and psychology**

- ☐ Transportation
- ☐ Energy
- ☐ Environment
- ☐ Urban planning
- ☐ Water
- ☐ Buildings
- ☐ N/A

⁎ **S2.3 Social relations and interactions**

- ☐ Transportation
- ☐ Energy
- ☐ Environment
- ☐ Urban planning
- ☐ Water
- ☐ Buildings
- ☐ N/A

⁎ **S2.4 Socioeconomic development**

- ☐ Transportation
- ☐ Energy
- ☐ Environment
- ☐ Urban planning
- ☐ Water
- ☐ Buildings
- ☐ N/A

⁎ **S2.5 Legislations and regulations**

- ☐ Transportation
- ☐ Energy
- ☐ Environment
- ☐ Urban planning
- ☐ Water
- ☐ Buildings
- ☐ N/A

⁎ **S2.6 Political context and interests**

- ☐ Transportation
- ☐ Energy
- ☐ Environment
- ☐ Urban planning
- ☐ Water
- ☐ Buildings
- ☐ N/A

⚹ **S2.7 Health and quality of life**

- ☐ Transportation
- ☐ Energy
- ☐ Environment
- ☐ Urban planning
- ☐ Water
- ☐ Buildings
- ☐ N/A

⚹ **S2.8 Arts and aesthetics**

- ☐ Transportation
- ☐ Energy
- ☐ Environment
- ☐ Urban planning
- ☐ Water
- ☐ Buildings
- ☐ N/A

⚹ **S2.9 Social problems (poverty, inequality,...)**

- ☐ Transportation
- ☐ Energy
- ☐ Environment
- ☐ Urban planning
- ☐ Water
- ☐ Buildings
- ☐ N/A

⚹ **S2.10 Ethics and philosophy**

- ☐ Transportation
- ☐ Energy
- ☐ Environment
- ☐ Urban planning
- ☐ Water
- ☐ Buildings
- ☐ N/A

Education block

E1–us,gs Do you consider that the university education received until the present has taught you about the following thematic areas?

- ☐ Culture and history
- ☐ Psychology
- ☐ Social communications and relations
- ☐ Socioeconomics
- ☐ Legislation
- ☐ Health and quality of life
- ☐ Politics
- ☐ Ethics and philosophy
- ☐ Arts and aesthetics
- ☐ Social problems
- ☐ None of the previous

E1–ns Do you consider that the university education that you are soon starting will teach you about the following thematic areas?

- ☐ Culture and history
- ☐ Psychology
- ☐ Social communications and relations
- ☐ Socioeconomics
- ☐ Legislation
- ☐ Health and quality of life
- ☐ Politics
- ☐ Ethics and philosophy
- ☐ Arts and aesthetics
- ☐ Social problems
- ☐ None of the previous

E1–p Do you consider yourself to include elements related to the following thematic areas in your classes?

- ☐ Culture and history
- ☐ Psychology
- ☐ Social communications and relations
- ☐ Socioeconomics
- ☐ Legislation
- ☐ Health and quality of life
- ☐ Politics
- ☐ Ethics and philosophy
- ☐ Arts and aesthetics
- ☐ Social problems
- ☐ None of the previous

E1–w Do you consider yourself to be knowledgeable in any of the following thematic areas?

- ☐ Culture and history
- ☐ Psychology
- ☐ Social communications and relations
- ☐ Socioeconomics
- ☐ Legislation
- ☐ Health and quality of life
- ☐ Politics
- ☐ Ethics and philosophy
- ☐ Arts and aesthetics
- ☐ Social problems
- ☐ None of the previous

E2 Do you think that civil engineers should be trained about the social aspects existing in civil engineering? Choose the most appropriate answer according to you.

- ○ Yes, through university education: adding social sciences subjects.
- ○ Yes, through university education: adding social contents to already existing subjects.
- ○ Yes, through conferences and seminars (not necessarily at university).
- ○ Yes, through professional experience, with no need of specific training.
- ○ No
- ○ Other (please specify)

E3 Following the previous question, which social aspects should be taught to civil engineers?

- ☐ Culture and history
- ☐ Psychology
- ☐ Social communications and relations
- ☐ Socioeconomics
- ☐ Legislation
- ☐ Health and quality of life
- ☐ Politics
- ☐ Ethics and philosophy
- ☐ Arts and aesthetics
- ☐ Social problems
- ☐ It is not necessary to raise awareness about these aspects
- ☐ Others (please specify)

Profession block

W1 How frequently do you think that civil engineers need knowledge on the following fields in their workplaces? Choose the most appropriate answer according to you.

	Never	Rarely	Occasionally	Frequently	Very frequently
Culture and history	○	○	○	○	○
Psychology	○	○	○	○	○
Social communications and relations	○	○	○	○	○
Socioeconomics	○	○	○	○	○
Legislation	○	○	○	○	○
Politics	○	○	○	○	○
Health and quality of life	○	○	○	○	○
Arts and aesthetics	○	○	○	○	○
Social problems	○	○	○	○	○
Ethics and philosophy	○	○	○	○	○

W2 How frequently do you think that the following skills are needed by civil engineers in their workplaces? Choose the most appropriate answer according to you.

	Never	Rarely	Occasionally	Frequently	Very frequently
Maths and Physics	○	○	○	○	○
Creativity and innovation	○	○	○	○	○
Leadership	○	○	○	○	○
Interpersonal skills	○	○	○	○	○
Analytical problem solving	○	○	○	○	○
Data analysis	○	○	○	○	○
Flexibility and adaptability	○	○	○	○	○
Teamwork	○	○	○	○	○
Conflict resolution	○	○	○	○	○
Communication skills (written and verbal)	○	○	○	○	○

Thank you very much for your participation. If you have comments or questions about it, you can write them below.

B.2. Descriptive statistics, reliability and validity

This section reports the most important statistics for each of the question blocks. In particular, the following statistics are reported:

- Mean.
- SD: standard deviation.
- α_{raw}: alpha based upon the covariances[1].
- α_{std}: standarized alpha based upon the correlations.
- G6(smc): Guttman's Lambda 6 reliability.
- $r_{average}$: average interitem correlation.
- r_{median}: median interitem correlation.
- r_{raw}: correlation of each item with the total score, not corrected for item overlap.
- r_{std}: correlation of each item with the total score (not corrected for item overlap) if the items were all standardized.
- r_{cor}: item whole correlation corrected for item overlap and scale reliability.
- r_{drop}: item whole correlation for this item against the scale without this item.

Note that different statistics may be reported for different questions due to the difference in the nature of the indicators, as well as to the discussion of the results made in the main body of the thesis.

B.2.1. General block

B.2.1.1. Question G1

Table B.1. Overall statistics of question G1

Mean	SD	α_{raw}	α_{std}	GL6	$r_{average}$	r_{median}
3.821	0.483	0.697	0.698	0.703	0.173	0.171

[1] A Cronbach's alpha coefficient equal or greater than 0.70 is considered to be indicative of an acceptable level of internal consistency.

Table B.2. Item statistics of question G1

	Mean	SD	r_{raw}	r_{std}	r_{cor}	r_{drop}
MATH	3.777	0.991	0.519	0.514	0.438	0.362
CHEM	3.719	0.936	0.553	0.559	0.503	0.412
CE	3.924	0.979	0.470	0.475	0.399	0.308
ARCHIT	3.648	0.917	0.509	0.516	0.437	0.365
MEDI	4.619	0.799	0.434	0.464	0.366	0.300
EDUC	4.403	0.931	0.430	0.438	0.338	0.272
AGRIC	3.735	1.019	0.522	0.517	0.433	0.362
PSYCH	3.653	1.037	0.536	0.527	0.452	0.375
ECON	3.873	0.975	0.520	0.520	0.436	0.366
HIST	3.403	1.022	0.493	0.478	0.401	0.327
ART	3.272	1.038	0.493	0.476	0.397	0.324

Table B.3. Item statistics if item removed of question G1

	α_{raw}	α_{std}	GL6	$r_{average}$	r_{median}
MATH	0.674	0.674	0.677	0.172	0.171
CHEM	0.666	0.666	0.667	0.166	0.169
CE	0.682	0.681	0.679	0.176	0.171
ARCHIT	0.674	0.674	0.678	0.171	0.169
MEDI	0.683	0.684	0.687	0.178	0.176
EDUC	0.688	0.688	0.689	0.181	0.176
AGRIC	0.674	0.674	0.680	0.171	0.169
PSYCH	0.671	0.672	0.676	0.170	0.166
ECON	0.673	0.673	0.679	0.171	0.169
HIST	0.679	0.681	0.679	0.176	0.171
ART	0.680	0.681	0.680	0.176	0.180

B.2.1.2. Question G2

Table B.4. Item statistics of question G2

	Mean	SD	Median
ECON	2.205	0.865	2
ENV	1.882	0.741	2
SOC	1.913	0.802	2

Table B.5. Item statistics of question G2

	1	2	3
		Economic	
Frequency	138	100	235
Proportion	0.292	0.211	0.497
		Environmental	
Frequency	161	207	105
Proportion	0.34	0.438	0.222
		Social	
Frequency	174	166	133
Proportion	0.368	0.351	0.281

B.2.1.3. Question G3

Table B.6. Item statistics of question G3

	Mean	SD	Median
Economic rentability	3.484	1.714	3
Costs	4.474	1.522	5
Emissions	3.389	1.545	3
Waste management	3.655	1.377	4
Adaptation to the context	3.922	1.670	4
Improvement of quality of life	2.076	1.420	1

Table B.7. Item statistics of question G3

	1	2	3	4	5	6
	Economic profitability					
Frequency	75	94	73	62	96	73
Proportion	0.159	0.199	0.154	0.131	0.203	0.154
	Costs					
Frequency	19	53	55	64	122	160
Proportion	0.04	0.112	0.116	0.135	0.258	0.338
	Emissions					
Frequency	67	81	99	105	69	52
Proportion	0.142	0.171	0.209	0.222	0.146	0.11
	Waste management					
Frequency	30	75	108	119	97	44
Proportion	0.063	0.159	0.228	0.252	0.205	0.093
	Adaptation to the context					
Frequency	42	75	79	81	74	122
Proportion	0.089	0.159	0.167	0.171	0.156	0.258
	Improvement of quality of life					
Frequency	240	95	59	42	15	22
Proportion	0.507	0.201	0.125	0.089	0.032	0.047

B.2.2. Specific block

B.2.2.1. Question S1

Table B.8. Overall statistics of question S1

Mean	SD	α_{raw}	α_{std}	GL6	$r_{average}$	r_{median}
4.133	0.555	0.648	0.649	0.627	0.236	0.232

Table B.9. Item statistics of question S1

	Mean	SD	r_{raw}	r_{std}	r_{cor}	r_{drop}
TRANSP	4.204	0.973	0.555	0.538	0.377	0.301
ENERGY	4.259	0.940	0.658	0.656	0.558	0.447
URB	3.847	0.926	0.571	0.567	0.417	0.335
ENV	4.245	0.949	0.637	0.636	0.529	0.415
WAT	4.537	0.825	0.573	0.596	0.481	0.369
BUILT	3.706	0.911	0.621	0.623	0.500	0.405

Table B.10. Item statistics if item removed of question S1

	α_{raw}	α_{std}	GL6	$r_{average}$	r_{median}
TRANSP	0.635	0.636	0.598	0.259	0.240
ENERGY	0.579	0.580	0.545	0.217	0.216
URB	0.621	0.623	0.588	0.249	0.240
ENV	0.591	0.591	0.556	0.224	0.225
WAT	0.609	0.610	0.565	0.238	0.226
BUILT	0.595	0.597	0.566	0.229	0.211

B.2.2.2. Question S2

Table B.11. Total responses for question S2

	ART	BEH	CULT	ECON	ETHICS	HEALTH	COM	LAW	POLIT	PROB
TRANSP	81	246	137	294	58	108	338	113	198	173
ENERGY	23	67	40	278	135	190	43	207	215	216
ENV	135	256	131	130	301	378	157	287	200	86
BUILT	338	103	319	96	64	47	152	122	104	194
WAT	19	115	61	141	122	358	37	150	99	270
URB	346	239	356	151	180	85	324	193	204	154

B.2.3. Education block

B.2.3.1. Question E2

Table B.12. Item statistics of question E2

Response	Frequency	Proportion
Yes, through university education: adding social sciences subjects.	208	0.553
Yes, through university education: adding social contents to already existing subjects.	129	0.343
Yes, through conferences and seminars (not necessarily at university).	5	0.013
Yes, through professional experience, with no need of specific training.	18	0.048
No	11	0.029
Other (please specify)	5	0.013

B.2.4. Professional block

B.2.4.1. Question W1

Table B.13. Overall statistics of question W1

Mean	SD	α_{raw}	α_{std}	GL6	$r_{average}$	r_{median}
3.510	0.610	0.824	0.824	0.835	0.319	0.321

Table B.14. Overall statistics of question W2

	Mean	SD	r_{raw}	r_{std}	r_{cor}	r_{drop}
CULT	3.243	0.889	0.674	0.677	0.633	0.582
PSYCH	2.810	0.988	0.607	0.603	0.549	0.489
COM	3.751	0.923	0.618	0.624	0.572	0.510
ECON	3.947	0.948	0.672	0.683	0.648	0.572
LAW	4.332	0.817	0.456	0.482	0.404	0.340
POLIT	3.387	0.995	0.635	0.641	0.591	0.521
HEALTH	3.863	0.965	0.612	0.613	0.551	0.498
ART	2.995	1.029	0.555	0.548	0.466	0.421
PROB	3.700	1.036	0.722	0.712	0.683	0.624
ETHICS	3.069	1.163	0.666	0.642	0.592	0.538

Table B.15. Item statistics if item removed of question W1

	α_{raw}	α_{std}	GL6	$r_{average}$	r_{median}
CULT	0.802	0.802	0.812	0.310	0.305
PSYCH	0.811	0.811	0.816	0.323	0.325
COM	0.809	0.808	0.815	0.319	0.319
ECON	0.802	0.801	0.808	0.309	0.319
LAW	0.823	0.825	0.827	0.344	0.340
POLIT	0.807	0.806	0.814	0.316	0.325
HEALTH	0.810	0.810	0.819	0.321	0.333
ART	0.818	0.817	0.826	0.332	0.341
PROB	0.796	0.797	0.805	0.304	0.303
ETHICS	0.806	0.806	0.815	0.316	0.319

Table B.16. Results of the chi-square tests of independence for question W1

	CULT	PSYCH	COM	ECON	LAW	POLIT	HEALTH	ART	PROB	ETHICS
Gender (df=4) (Male, Female)	6.61	3.45	2.63	2.54	0.71	1.49	3.31	5.13	6.06	4.01
Group (df=16) New (A), undergraduate (B), graduate students (C), professors (D), practitioners (E)	83.87*** A:E*** B:E*** C:E*** D:E***	40.24*** B:E* C:E** D:E*	53.02*** B:C* C:E*** D:E*	88.29*** N:W*** U:W*** G:W*** P:W***	46.08*** U:P* U:W* G:W*	99.19*** N:W*** U:P*** U:W*** G:P** G:W*** P:W*	86.97*** N:W*** U:W*** G:W*** P:W**	50.81*** N:W*** N:G* U:W* G:W* P:W***	97.93*** N:W*** U:W*** G:W*** P:W***	53.42*** N:W* U:W*** G:W*** P:W***
Age (df=40) <18, 19-21, 22-25, 26-29, 30-34, 35-39, 40-44, 45-54, 55-64, >65	46.34	47.59	55.66	75.05*** 18:34* 18:35* 18:45* 22:30** 22:35* 22:40* 22:45*	83.26*** 21:30* 21:40* 22:30**	119.20*** 18:22**18:35** 18:45*21:30* 21:35** 21:45* 22:30*** 22:35*** 22:40** 22:45*** 22:55*** 22:65* 22:35* 35:55*	59.86* 18:40* 18:45** 18:55* 19:45* 19:55* 21:40* 21:55** 22:40** 22:45** 22:55*	45.18	68.90** 22:35* 22:40* 22:45*	53.15
Max studies (df=24) High school (H), vocational training (V), degree (D), master (M), PhD (P)	75.82*** H:V* H:D** H:M* D:P** M:D** V:D* V:M**	28.64	47.76** D:P**	68.98*** H:D*** H:M*** M:P*	34.76	58.92*** H:D** H:M** H:P** D:P* D:M*	75.8*** H:D*** H:M** D:M*	44.08** H:D* D:P*	66.75*** H:D*** H:M* D:P*** M:P* V:M* D:M**	38.08* D:P* M:D*
Activities (df=4)										
cult (Yes, No)	1.95	10.22*	7.28	3.65	10.45*	21.29	4.46	2.89*	7.34*	4.23*
physical (Yes, No)	2.79	5.05	8.83	1.63	2.22	3.3	9.44	4.3	3.75	3.14
creative (Yes, No)	3.01	4.8	7.46	3.14	1.19	1.24	1.89	17.56**	5.17	2.39
develop (Yes, No)	3	1.54	7.77	2.38	2.61	1.7	5.39	5.57	20.41***	9.79*
service (Yes, No)	3.86	3.51	2.1	6.28	3.48	3.49	4.56	0.72	6.33	5.83
learning (Yes, No)	5.81	1.55	5.04	6.79	2.87	2.61	3.97	3.37	6.32	6.68
no (Yes, No)	2.72	2.88	0.81	1.93	2.69	0.82	3.48	5.65	3.82	7.88

B.2.4.2. Question W2

Table B.17. Overall statistics of question W2

mean	sd	α_{raw}	α_{std}	GL6	$r_{average}$	r_{median}
4.317	0.450	0.807	0.809	0.815	0.279	0.294

Table B.18. Item statistics of question W2

	Mean	SD	r_{raw}	r_{std}	r_{cor}	r_{drop}
INFORM	4.277	0.768	0.456	0.469	0.384	0.320
COMM	4.526	0.608	0.482	0.523	0.457	0.380
CONFL	4.341	0.805	0.678	0.668	0.630	0.574
CREAT	4.142	0.874	0.641	0.623	0.571	0.518
ANALY	4.279	0.784	0.614	0.608	0.549	0.500
FLEX	4.375	0.708	0.625	0.641	0.592	0.526
INTER	4.240	0.760	0.628	0.639	0.595	0.521
LANG	4.249	0.787	0.596	0.592	0.534	0.478
MATH	4.034	0.932	0.547	0.505	0.437	0.393
PROBL	4.336	0.829	0.644	0.621	0.582	0.529
TEAM	4.686	0.554	0.524	0.564	0.493	0.436

Table B.19. Item statistics if item removed of question W2

	α_{raw}	α_{std}	GL6	$r_{average}$	r_{median}
INFORM	0.806	0.807	0.808	0.295	0.307
COMM	0.799	0.802	0.801	0.288	0.294
CONFL	0.780	0.785	0.789	0.267	0.290
CREAT	0.786	0.790	0.794	0.273	0.282
ANALY	0.788	0.792	0.797	0.276	0.300
FLEX	0.786	0.788	0.793	0.271	0.281
INTER	0.786	0.788	0.792	0.271	0.293
LANG	0.790	0.794	0.797	0.278	0.294
MATH	0.801	0.803	0.803	0.290	0.294
PROBL	0.785	0.790	0.790	0.274	0.293
TEAM	0.796	0.797	0.802	0.282	0.294

Table B.20. Results of the chi-square tests of independence for question W2

	INFORM	COM	CONFL	CREAT	ANALY	FLEX	INTER	LANG	MATH	PROB	TEAM
Gender (df=4) (Male, Female)	8.74*	0.68	5.76	1.09	7.64	7.77	6.04	1.27	2.83	2.52	0.77
Group (df=16) New (A), undergraduate (B), graduate students (C), professors (D), practitioners (E)	16.83	14.67	60.44*** N:W**D:P*** D:W***G:W***	67.58*** N:W***D:W*** G:W*** P:W**	28.17* N:W**	12.17	21.4	44.61*** N:W* D:W**	118.73*** N:W*** N:D** D:M* D:P**D:W*** M:W** P:W*	58.67*** N:W*** D:W** M:W**	10.62
Age (df=40) <18, 19-21, 22-25, 26-29, 30-34, 35-39, 40-44, 45-54, 55-64, >65	41.89	28.99	68.77** 19:45**21:30** 21:45**21:55** 21:65**22:45**	68.57** 18:45* 22:26* 22:45*	55.19	21.11	37.92	62.03* 21:45*22:26* 26:35*26:45*	123.73*** 18:21*18:30*** 18:45*** 19:30* 19:45* 21:25* 21:40** 21:55** 21:65*	63.54* 18:45*	17.48
Max studies (df=24) High school (H), vocational training (V), degree (D), master (M), PhD (P)	36.76** H:D* D:M*	17.43	70.57*** H:D* H:M*** H:P***	52.39*** H:D* H:M** H:P*	19.57	16.42	10.65	30.04	88.29*** H:D*** H:M*** H:P***	41.04* H:D* H:M* H:P*	7.32
Activities (df=4)											
cult (Yes, No)	2.52	4.38	4.52	5.78	1.17	1.18	0.8	0.89	8.05	2.84	6.42
physical (Yes, No)	4.06	2.8	3.39	6.8	3.87	2.4	2.61	5.3	0.6	8.84	2.77
creative (Yes, No)	0.7	1.4	0.35	1.62	3.76	1.34	0.42	1.47	8.45	4.94	6.31
develop	5.09	8.14*	1.48	2.46	2.04	6.49	4.12	5.91	1.73	1.54	0.97
service	6.67	3.91	1.89	3.31	2.87	1.81	2.29	3.01	0.65	2.39	0.92
learning	6.44	7.39	3.42	1.49	4.36	0.42	7.29	7.16	1.88	7.99	0.81
no	0.48	4.75	5.86	6.81	3.42	2.84	11.53*	1.91	5.88	8.18	2.06

C Interviews

In this Appendix, the informed consent form that was sent to the Spanish interviewees (Section C.1), the guide for the questions to be asked in the interview (Section C.2), and the codes developed in the analysis stages are presented (Section C.3).

C.1. Informed consent form

Informed consent form

Title of project: Analysis of perceptions in civil engineering academia towards social aspects

Principal researcher: Irene Josa i Culleré (PhD Candidate)

Institution: Escola Tècnica Superior de Camins, Canals i Ports, Universitat Politècnica de Catalunya

This Informed Consent Form has two parts:

- Information Sheet (to share information about the study with you)
- Certificate of Consent (for signatures if you choose to participate)

You will be given a copy of the full Informed Consent Form.

Part I: Information Sheet

Introduction

I am a PhD student at Polytechnic University of Catalonia. I am doing research on the perceptions of researchers and professors towards social aspects. This document gives you information and invites you to be part of this research.

Purpose of the project

The only purpose of the project is research. I am analysing the perceptions of key stakeholders on the inclusion of syllabus contents related to the social sciences such as ethics and development in standard civil engineering curricula. This forms part of the broader framework of my research that involves examining the interrelations between infrastructure and society. Considering the great impact that infrastructure has on society, I believe there is still a knowledge gap concerning how different types of infrastructure have different effects on social areas such as wellbeing, poverty and inequality. As such, my thesis aims to analyse the relationship between social sciences/humanities and civil engineering at different levels in order to shed more light on the most efficient ways to address this gap.

Type of research intervention

This research will involve your participation in an interview that will take about one hour.

Participant selection

You are being invited to take part in this research because I feel that your experience as a professor in the Civil and Environmental Engineering Department of University College of London can contribute significantly to my understanding and knowledge of the research topic.

Voluntary participation

Your participation in this research is entirely voluntary. It is your choice whether to participate or not.

Procedures

I am asking you to help me learn more about the relationship between civil engineering and social sciences/humanities. I am inviting you to take part in this research project. If you accept, you will be asked to participate in an interview with myself.

The interview will take place through a virtual meeting platform to be agreed upon, such as Zoom, Microsoft Teams or Skype. If you do not wish to answer any of the questions during the interview, you may say so and the interviewer will move on to the next question. No one else but the interviewer will be present unless you would like someone else to be there. The information recorded is confidential, and no one else except Irene Josa i Culleré will access to the information documented during your interview. The entire interview will be recorded, but no-one will be identified by name on the file name. The information recorded is confidential, and no one else except Irene Josa i Culleré will have access to the recording. The recording will be kept until one year after the thesis defence of Irene Josa i Culleré.

Duration

The interview will last for about one hour. The research project takes place over six months approximately.

Risks

There is a very low risk that you may share some personal or confidential information by chance, or that you may feel uncomfortable talking about some of the topics. However, you do not have to answer the questions if you feel the question(s) are too personal or if talking about them makes you uncomfortable.

Benefits

There will be no direct benefit to you, but your participation is likely to help me find out more about how to improve the education of civil engineers by introducing social aspects.

Reimbursements

You will not be provided any incentive to take part in the research.

Confidentiality

I will not be sharing information about you to anyone. The information that I collect from this research project will be kept private. Any information about you will have a number on it instead of your name. Only I will know what your number is. It will not be shared with or given to anyone except. Details in the interview that may reveal your identity or the identity of the people you speak about will be disguised. Disguised extracts of the interview may be quoted in a thesis dissertation and a paper.

Sharing the results

Nothing that you say during the interview will be attributed to you by name. Following the interviews, I may publish the results so that other interested people may learn from the research. No personal information that can be used to identify the interviewee will be published. General conclusions from all the interviews carried out will be used. However, with prior consent from the interviewees, to thank them for their time, the interviewer would like to include their names in the acknowledgements section of any publication which could emerge from the findings.

Right to refuse or withdraw

You do not have to take part in this research if you do not wish to do so. Even if you agree to participate now, you can withdraw at any time or refuse to answer any question with any consequences of any kind.

Part II: Certificate of consent

Statement by the participant

I have read the foregoing information. I have had the opportunity to ask questions about it and any questions I have been asked have been answered to my satisfaction. I consent voluntarily to be a participant in this study.

Yes □ No □

Name of the participant ____________________________

Date ________________

Statement by the researcher

I confirm that the participant has not been coerced into giving consent, and the consent has been given freely and voluntarily.

Name of the researcher ____________________________

Date ________________

C.2. Guiding questions

Introduction

Do you consider that you have knowledge or interest in the social sciences and humanities?
What do you think are the most important social aspects related to civil engineering? And with your specialty?
Do you think that the social sciences and humanities can contribute to the work of civil engineers?
What specific areas do you think are most important?
And vice versa?

Education

What do you think are the three biggest challenges in civil engineering education today?
Who do you think has an important role in trying to solve these challenges?
Do you think aspects of the social sciences and humanities should be included in civil engineering programs? Why?
Yes → Specifically, what aspects do you think should be included?
Yes → In what way and at what time?
Yes → Who?
No → Why? Do you think it should be other disciplines that take care of these aspects?
Do you think there are drawbacks in introducing SSH in civil engineering programs?
In the subjects you teach, do you include aspects related to the social sciences and humanities?

Yes → Specifically, what aspects does it include?

Yes → What are the biggest challenges for including such aspects?
How do you try to overcome these challenges?

Yes → What are the most helpful aspects to include these aspects?

Yes → What opinion do you think students have in this area?

No → Why? Do you think there are no aspects of SSH related to your discipline?

No → What are the biggest challenges you face to include such aspects?

No → What opinion do you think students have in this area?

Do you think that aspects related to the social sciences and humanities are included in other subjects of the same program?
What perception do you think other teachers of the same program have in relation to these elements?

Research

In your field of research, does it include aspects related to the social sciences and humanities?
What direction do you think civil engineering education will follow in the coming years?
Do you think there is someone in your School that I should contact regarding this matter?

C.3. Coding

Table C.1 includes all the codes created during the analysis process. Note that the original codes were in Spanish, and they have been translated here into English.

Table C.1. All the codes, alphabetically ordered

“Maria” subject	2008 crisis
Ability to change	Academic career
Adapting social issues to the context of CE	Administrative structures
Admiration to other teachers	Age
All types of professor contracts	American model
Appreciation towards teachers	Arousing interest in social sciences
Art	Articles
Asking important questions	Balance
Barriers	Barriers by students
Barriers in interdisciplinary team	Barriers to including SSH in CE
Before, importance was given to basic sciences	Being able to influence school issues
Being already in good position	Being more than a technician
Being very engineer	Believing that what is yours is the most important
Believing that you are incapable	Bologna process
Bureaucracy	Centre of Cooperation for Development
Challenges in civil engineering education	Changes
Changes in HE	Changes in studies
Changes in study plans	Changes in the future
Changes you would like to see in the future	Chemistry subject
Civil engineering contribution to social sciences	Civil engineering the rare branch
Civil engineers’ demand	Collaboration between different groups
Colleges	Commissions
Company participation	Comparison with the Anglo-Saxon model
Competitiveness in the university	Complaints from teachers to students
Complicated start	Conception of the SSH
Concrete	Conflicts at work
Consolidating	Consultancies (research)
Contextualising the subject with social issues	Contradictions
Cooperation	Cooperation projects
Corporatism	Corruption
COVID	Creation of new degrees
Creation of new teaching positions	Credits
Critical thinking	Culture of effort
Daring to express doubts (students)	Daring to express yourself (students)
Debates between teachers	Debates in class
Department pressure	Departmental structure
Departments + credits	Development
Differences between generations	Differences between groups
Differences in language SSH - CE	Different areas of CE
Different levels of involvement	Differential importance between CE sectors
Difficult to include SSH in your subject	Difficulties encountered
Difficulty conducting debates	Difficulty making changes
Difficulty of the degree	Disadvantages of social sciences in CE
Disappearance of certain subjects	Discussion spaces

Table C.1 continued from previous page

Distributing credits	Doctoral student
Economic issues	Education getting easier
Education in values	Educational models
Effort needed to include SSH	Elitism
Empathy	Emphasis on research
Importance of interdisciplinary groups in class	Engineer person
Engineering tradition	Enjoying the interview
Environmental issues	Epistemology
Evaluation	Evolution of HE
Evolution of perception towards the social	Evolution of research topics
Evolution of social issues	Excessive unionization
Expensive education	Facilities
Feeling of inferiority	Feeling welcomed
Field trip	Figure of the associate professor
First year	Gaining knowledge in SSH outside college
Gaining weight in the program	Gender
Good contribution vs paper machine	Good experiences with students
Having a different vision	Having a resume
Having made mistakes	High school
Hiring more teachers	Hour quotas
How to include SSH subjects	Hyperspecialization
CE + SSH professional work	Importance of communication
Importance of cultural differences	Importance of teaching land use planning
Importance of the mathematical part	Importance of who coordinates
In some subjects it is complicated	Incentives
Including social sciences in CE education	Inclusion of social sciences in the subject
Inclusivity	Industry
Informal spaces for debate	Institute of Education Sciences
Institutional relations	Interdisciplinary team
Interest has been increasing	Companies want students to know about SSH
Interest towards social sciences	Internal resistors
International mobility	Investigation
Investigation Group	Job stability
Just subjects is not enough	Knowledge (what?)
Laboratory	Lack of dialogue
Lack of dialogue between teachers	Lack of resources
Lack of training in social issues	Lack of transparency
Latin America	Lazy students
Leadership	Legislation in urban planning
Level with which you reach the university	Losing teaching credits
Mainstreaming of social issues	Making the studies attractive
Management team	Many topics to include
Marketing	Master's degree
Methods (how?)	Mobility
Mobilization	Moral dilemma activity
Most powerful sectors	Motivation for civil engineering
Motivation to include SSH	Multiple choice test
Necessity	Need for debate between teachers
Need for renovation	New teacher positions

Table C.1 continued from previous page

New Topics in civil engineering	NGO
Not adding a lot of social aspects	Not getting too involved
Not including social sciences apart	Number of exams
Number of places	Number of students
Old School	Online classes
Opening the mind to the world around us	Opposition of teachers
Optional vs mandatory	Perception on holistic profile
Perception towards a sociologist professor	Personal interest
Pessimism regarding the current system	Politically correct SSH in CE
Politicization	Politics
Powerful departments	Preparedness to change
Prestige of the profession	Priority
Problems of publishing on social topics	Professor teaching it (Who?)
Progressive incorporation of SSH in CE	Project financing
Project justification	Project-based learning

Table C.2. Categories and subcategories generated during open coding

Themes	Subthemes	Examples of coding topics
Teaching and learning (professors)	Career path	Professional career, academic career, field of specialty, subject taught
	Interests	Personal interests, motivation for civil engineering, interest towards social sciences
	Attitude	Professors' attitudes, different levels of involvement, professor's commitment
	Perception towards the integration of social topics in the CE program	Adapting social topics to the CE context, specific topics to include, progressive integration, integration being difficult in some subjects
	Resources	Lack of resources, time, too many topics to include in the subjects, losing teaching hours
Teaching and learning (students)	Age	Student's age, maturity level of students, young people
	Interests	Motivation for studying, motivation for studying civil engineering, extracurricular interests
Teaching and learning (others)	General topics of civil engineering education	Challenges in civil engineering education, difficulty of the degree, number of applications, price of the degree
Research	Research group	Working in silos, interdisciplinary teams, barriers for interdisciplinary teams, research funding
	Research field	Research in the intersection CE-SSH, specialisation, hyper-specialisation
	Research dissemination	Quality of publications, too much publishing, emphasis on publishing, problems in publishing in interdisciplinary areas
University environment	Departments	Departmental structure, powerful departments, pressure from the departments
	Governance	University's Social Committee, executive team, institutional relationships, transparency
Industry	Role of the civil engineer	Understanding what an engineer is, understanding the role of a civil engineer, evolution of civil engineering
	Civil engineering subfields	
	Characteristics of the civil engineer	Humanist engineer, rigidity, elitism, empathy, being "very engineer"
The social in civil engineering		Conception, contribution of SSH to CE, evolution of perception