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Method to develop social impact pathways: A case on carbon- and steel reinforced concrete

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ABSTRACT

This research aims present a new approach to perform type II Social Life Cycle Assessments (S-LCAs), impact pathways (IP), applied to Carbon- and Steel Reinforced Concrete. The application of IP requires determining causal relations and characterization factors. However, the literature indicates to persistent deficiencies in identifying empirical cause-effect relations and scientific development of characterization factors. To advance IP application, a new approach by using structural equation modeling (SEM) to develop IP is presented in this research. Primary data was collected by questioning workers based on 8 inventory indicators for 3 social subcategories. The results showed where the causal relations could be empirically proven or not, indicating that is suitable for creating social IPs based on real cause-effect chain. For future research, it is recommended to apply the developed model on a larger sample to verify the proposed method and discuss the extent to which complex social issues can be generalized.

1. Introduction

With about 37 percent of global CO_2 emissions and an increasing trend in energy consumption, the construction sector currently finds itself in a situation in which solutions to drive sustainable development need to be established (UNEP, 2021). One attempt in this direction is the replacement of SRC, as the most widely used material in the construction sector (Leyder et al., 2021). A potential solution replacing Steel Reinforced Concrete (SRC) could be CRC. With a substantial reduction of resources, it could represent an environmentally and economically more sustainable alternative (Backes et al., 2023; Eamon et al., 2012). However, to make a well-founded statement about whether CRC is more sustainable than SRC, the third dimension of sustainability, the social perspective, must also be assessed (Backes and Traverso, 2023; Finkbeiner et al., 2010). At the international level, social considerations are already accorded great importance, as exemplified by the SDGs (United Nations THE 17 GOALS) and the EU Green Deal, in which a just transition towards a green economy is considered as one key goal (The European Green Deal, 2019).

Established solutions like the certification scheme DGNB, Leed(s), and Level(s) mainly place their focus on the use stage, focusing on aspects like user comfort (Deutsche Gesellschaft für Nachhaltiges Bauen - Dgnb, 2024; Level(s): Putting circularity into practice, 2021; U.S. Green Building Council, 2023). However, other life cycle stages and stakeholder categories can also have a major impact on the social sustainability performance of building products. In case studies on Social Life Cycle Assessment (S-LCA), a focus can be found on the stakeholder category Worker in the production stage. Yet, no S-LCA has been performed so far evaluating CRC as a potential substitution for SRC. Multiple type I S-LCAs (reference scale approach) could be found for steel and concrete. However, in type I S-LCAs social performance is assessed while assuming a causal relation to the actual endpoint impact (United Nations environment programme, 2020). If the causal relation and thus the actual impact the product creates is pursued on an investigation, e.g. on the workers' well-being, a type II S-LCA (impact pathway) needs to be performed (United Nations environment programme, 2020; Neugebauer et al., 2017). A type II S-LCA could not be found in the literature for SRC as well as CRC. While models have already been developed for environmental sustainability assessments in which the relations between emissions and impact categories are specified by characterisation factors, developing empirical and evidence-based characterization factors is still lacking for S-LCAs. Approaches can be found in the literature that attempt to develop characterisation factors for social sustainability aspects (Neugebauer et al., 2014; Araujo et al., 2021), but these do not make use of sector-specific primary data for impact pathways of a specific product category, using statistical models that can prove the

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existence of causality and, moreover, derive the characterization factors in a robust and mathematical way. This study presents a method that allows the development of impact pathways and, in doing so, the definition of characterisation factors for the future. The method is presented using the case of steel and carbon reinforced concrete. The research question: "What are social impacts for workers arising from the production of a CRC and an SRC building component?" is posed. Within this framework it is assessed whether significant differences between social impacts in the SRC and CRC production industry are existent. Furthermore, causal relations among indicators, midpoint impacts, and the endpoint impact workers' well-being are evaluated to create a social impact pathway for the production of a CRC and SRC building component. For that, a type II S-LCA with three midpoint impact indicators, including eight inventory indicators on the social sustainability performance of CRC during the production stage (Gate to Gate), is developed. For the development of the impact pathway, a new approach using structural equation modelling (SEM), is resented. While SEM is a well-established method in social science, it has not been applied for impact pathways development in the S-LCA field. For data collection, site-specific data is collected using a questionnaire. The focus is set on the stakeholder group Worker. By doing so, this study not only applies S-LCA for the first time for a CRC and SRC building component, but further enables impact pathway development based on structural equation modelling for applications.

2. Theoretical background

2.1. Social sustainability assessment

To assess potential and actual social impacts throughout the whole life cycle of a product, an S-LCA should be performed in accordance to the Guidelines of S-LCA by the UNEP based on the ISO 14040 and 14044 standards (United Nations environment programme, 2020; Deutsches Institut für Normung, 2021a; Deutsches Institut für Normung, 2021b). Furthermore, the recently published ISO 14075 provide a standardization for the method (International Organization for Standardization, 2024). Accordingly, an S-LCA follows the same phases as an environmental life cycle assessment (LCA): 1) Goal and scope definition, 2) inventory, 3) impact assessment, and 4) interpretation. Within the inventory, it is differentiated between generic data from databases, and site-specific data e.g. through surveys. When assessing the impact, there are two different methods that can be chosen from. Type I S-LCA is the reference scale approach, which is used to assess social performance. Type II S-LCA on the other hand is the impact pathway approach, aiming to assess consequential social impacts through characterizing the cause-effect chain (United Nations environment programme, 2020). As specified in the newly published ISO/FDIS 14075, the impact assessment includes classification and characterization of the inventory result to the selected impact categories (International Organization for Standardization, 2024). It is recognised in the literature that one of the main difficulties of S-LCAs is in tracking of social impact pathways (Pollok et al., 2021). For the development of social characterization factors, it is recommended to use company or sector-specific data (Ugaya et al., 2023).

2.2. State-of-the-art

To further evaluate the social sustainability performance in the construction sector, and specifically of CRC elements, the current state of the art was investigated.

For that, a literature review was conducted within the platforms Scopus, Web of Science, and ScienceDirect from 2015 to 2023 (May). Synonyms for S-LCA (Social Impact Pathway, Social Sustainability, SLCA) were combined with synonyms for CRC (Carbon Concrete, Fiber Reinforced Concrete, Carbon Reinforced Concrete, Carbon Reinforcement), Concrete (Cement), and SRC (Steel, Steel Reinforcement, Steel Concrete, Steel Reinforced Concrete). A first scan of title, abstract, and keywords resulted in 35 studies. No Type II S-LCA study could be found in the literature for the assessment of the potential social impacts of CRC and SRC. However, after further investigations, 12 studies performing type I case studies could be found for at least one of the relevant product categories. Furthermore, 8 other studies providing valuable insights for the further proceedings of this study.

A focus was set on the stakeholder category Worker. From the 12 type I studies found, all of them included the stakeholder category Worker (Caruso et al., 2022; Oladazimi et al., 2021; Balasbaneh et al., 2018, 2021; Balasbaneh and Marsono, 2020; Penadés-Plà et al., 2020; Zheng et al., 2019; Roh et al., 2018; Kono et al., 2018; Sánchez et al., 2019; Singh and Gupta, 2018; Dong and Ng, 2015), most of them even including more than one stakeholder category. The production and construction stages of the product system were also always included, while other life cycle stages were only taken into consideration in 7 of the studies (Caruso et al., 2022; Balasbaneh et al., 2018, 2021; Balasbaneh and Marsono, 2020; Penadés-Plà et al., 2020; Zheng et al., 2019; Singh and Gupta, 2018). It became apparent that most studies included the subcategory health and safety within their assessment. However, it was not always the same terminology used. While some studies used the nomenclature "health and safety" as in the UNEP Guidelines (Caruso et al., 2022; Oladazimi et al., 2021; Zheng et al., 2019; Roh et al., 2018; Sánchez et al., 2019; Singh and Gupta, 2018; Dong and Ng, 2015), others focused only on the indicator occupational accidents (Balasbaneh et al., 2021; Balasbaneh and Marsono, 2020). In general, it could be seen that the wording used for assessed impact categories, differs between the publications and is not always aligned with the UNEP Guidelines (United Nations environment programme, 2020).

To gain an overview about social issues of concern, indicators in the stakeholder category Worker mentioned in previous studies related to the production of CRC and/or SRC were categorized and collected in Table 1.

Although this overview shows a fairly complete picture of the topics according to the UNEP Guidelines, no study could be found that actually examined all subcategories in their entirety in an S-LCA. Furthermore, no study was found that carried out a comparative S-LCA of CRC and SRC. The study that came closest to it was the one by Backes and Traverso (2023). Here, a Social Hotspot Database (SHDB) screening was carried out for CRC in order to identify its most relevant social subcategories. However, once again, the SHDB categorization do not use the terminology as of the UNEP Guidelines. Nevertheless, this study provides an important basis for the present work, in particular. Furthermore, Backes and Traverso (2023) call for an S-LCA to be carried out for CRC as a possible alternative to SRC, which emphasises the relevance of our study (Backes and Traverso, 2023). This lack in S-LCA applications indicates a need not only in examining social impacts of CRC, but further the development of impact pathway methodologies.

In existing literature, the usage of methods such as SEM to infer causality is suggested for investigating impact pathways (Sureau et al., 2020). De Araujo et al. also recognised this potential of the method and applied it to impact pathway development, but using secondary data-sources. (Araujo et al., 2021). Thus, no sector-specific primary data, as recommended in other studies for the development of impact pathways (Ugaya et al., 2023), were used. Within the conducted literature review in the reinforced concrete sector, no study presented structural equation modeling (SEM) as a technique to verify the real causality between indicators and mid-point impact, and between mid-point impact and the end-point impact, and the strength of these links by using the technique to derivate the characterization factors. It is noteworthy that both the verification of causality and the development of characterization factors are requirements to the application of an impact pathway approach (United Nations environment programme, 2020).

SEM is a powerful technique to test and evaluate multivariate causal relationships, testing the direct and indirect effects on pre-assumed

Table 1
Social issues of concern from literature review.

Social issue	Source
Training	Zheng et al., 2019), Roh et al., 2018 , Venkatesh et al., 2016, Wang et al., 2021
Health and safety	Caruso et al., 2022), Oladazimi et al., 2021 (Zheng et al., 2019, Roh et al., 2018, Sánchez et al., 2019, Li et al., 2020, Singh and Gupta, 2018, Venkatesh et al., 2016, Dong and Ng, 2015, Berriel et al., 2018, Jain and Singh, 2020, Wong and Loo, 2022), Balasbaneh and Marsono, 2020 , Backes and Traverso, 2023, Penadés-Plà et al., 2020
Freedom of association and collective bargaining	Caruso et al., 2022), Roh et al., 2018 (Backes and Traverso, 2023), Dong and Ng, 2015, Balasbaneh and Marsono, 2020, Penadés-Plà et al., 2020
Child labor	Caruso et al., 2022), Roh et al., 2018, Venkatesh et al., 2016, Dong and Ng, 2015
Fair salary	Caruso et al., 2022), Oladazimi et al., 2021 (Penadés-Plà et al., 2020, Kono et al., 2018, Roh et al., 2018, Singh and Gupta, 2018, Dong and Ng, 2015, Jain and Singh, 2020, Balasbaneh et al., 2021, Balasbaneh et al., 2018
Working hours	Caruso et al., 2022), Zheng et al., 2019 (Kono et al., 2018, Roh et al., 2018, Sánchez et al., 2019, Dong and Ng, 2015, Berriel et al., 2018, Penadés-Plà et al., 2020
Forced labor	Caruso et al., 2022), Kono et al., 2018 (Roh et al., 2018, Singh and Gupta, 2018, Dong and Ng, 2015, Penadés-Plà et al., 2020
Equal opportunities/ discrimination	Caruso et al., 2022), Roh et al., 2018 (Dong and Ng, 2015, Penadés-Plà et al., 2020, Wang et al., 2021, Venkatesh et al., 2016
Social benefits/social security	Caruso et al., 2022), Roh et al., 2018 (Backes and Traverso, 2023, Penadés-Plà et al., 2020, Wang et al., 2021
Local employment/Human resource usage	Oladazimi et al., 2021), Singh and Gupta, 2018 (Dong and Ng, 2015, Leyder et al., 2021, Wang et al., 2021, Jain and Singh, 2020, Wong and Loo, 2022, Balasbaneh et al., 2018
Laws and Regulations	Penadés-Plà et al., 2020), Backes and Traverso, 2023 , Wang et al., 2021, Singh and Gupta, 2018
Employment relationship	Roh et al., 2018, Wang et al., 2021, Jain and Singh, 2020

causal relationships (Fan et al., 2016). Finally, SEM is a combination of two statistical methods: confirmatory factor analysis (CFA) and path analysis. From the CFA, it is verified whether the questions used to collect the data are really assessing the measured indicator, and path analysis relies on regression modeling to check causality among variables. Therefore, SEM is a comprehensive technique that covers all the necessary requirements encompassed in a social impact pathway approach. By applying SEM for an impact pathway development, this study aims to close the gaps discovered throughout the literature review, and advance applicability of the S-LCA methodology in construction.

3. Methodology

In the following section, the methodological steps taken are described. This study performs a case study of a type II S-LCA with the proposed method and following the UNEP guidelines (United Nations environment programme, 2020). Given that a S-LCA should follow the four steps of an LCA: Goal and scope definition, life cycle inventory, life cycle impact assessment, and interpretation (United Nations environment programme, 2020; Deutsches Institut für Normung, 2021a; Deutsches Institut für Normung, 2021b), Fig. 1 illustrates the methodological steps taken within these four phases.

3.1. Goal and scope definition

The goal of this S-LCA is to determine the impact resulting from the production of a carbon reinforced concrete element compared to a steel reinforced concrete element. For the type II S-LCA, a building product made from CRC compared to SRC is assessed during its production stage. This implies the gate-to-gate analysis of the processing of raw materials and production of a CRC/SRC component. The life cycle stage of raw material extraction was excluded from this study, due to limited data availability. Additionally, the inclusion of raw material extraction would also entail the interviewing of workers outside Europe (Backes and Traverso, 2023). Since this study focuses on the European construction industry, only gate-to-gate production is considered in the exemplary application. Furthermore, production processes including electricity and transportation were cut out as this study aimed to mainly assess and compare the processes with a direct link to the production of CRC and SRC. Fig. 2 summarizes the system boundaries of this study.

A focus was placed on the stakeholder group Worker, as it was found as the most relevant within the production stage of a CRC element in the literature review (Backes and Traverso, 2023). Defining a functional unit (FU), similarly to the LCA, poses difficulties for an S-LCA. In the literature, it has already been recognised that it is often not possible to

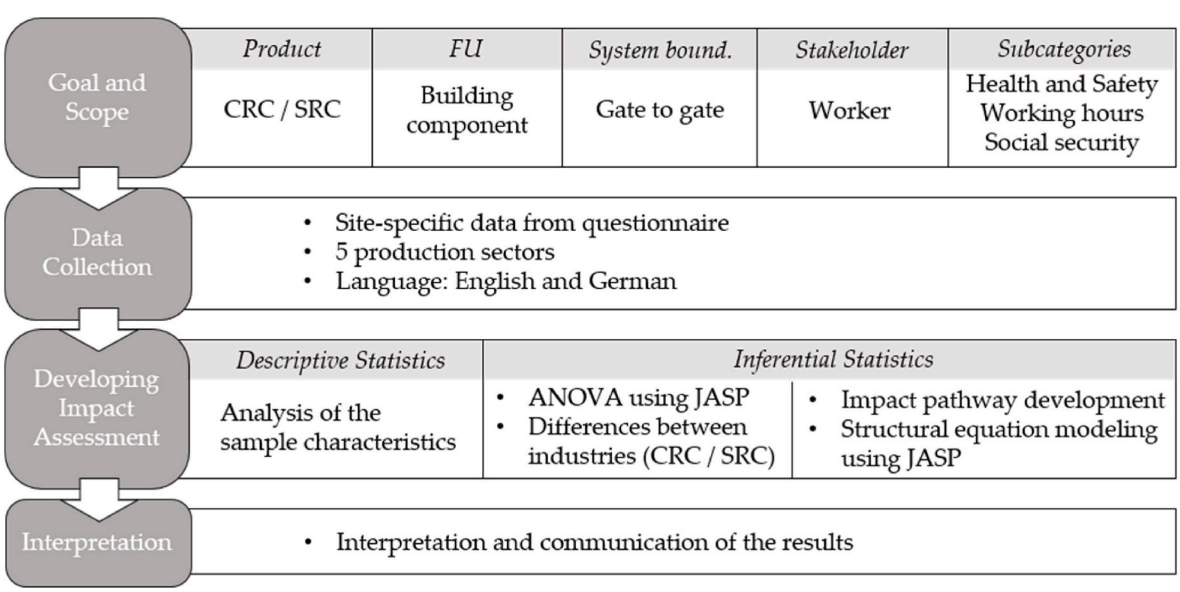

Fig. 1. Flow chart methodical steps.

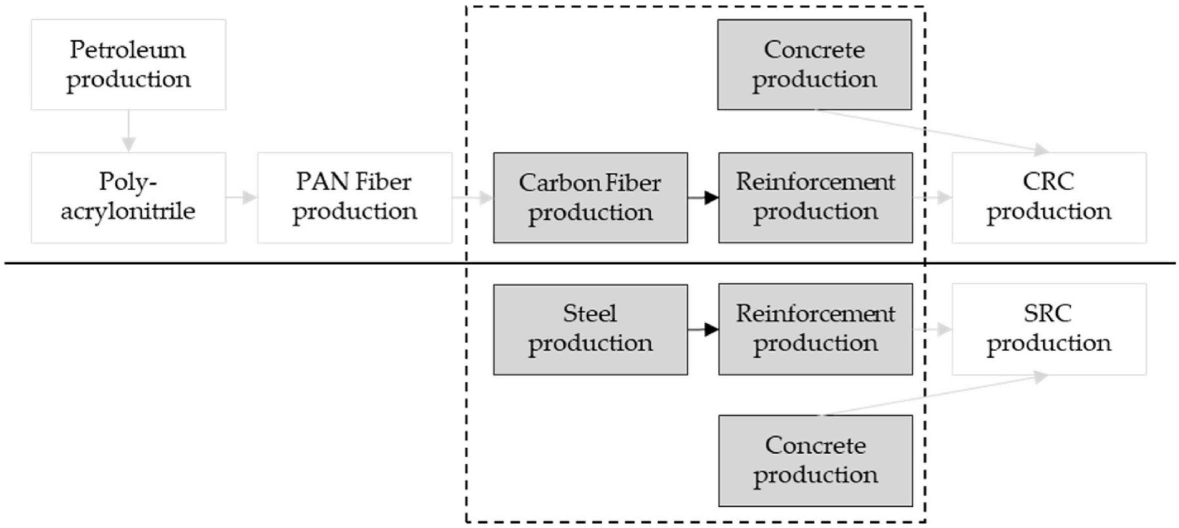

Fig. 2. System boundaries based on (Backes and Traverso, 2023; Backes et al., 2021).

define an FU to measure the social performance of a specific product system but rather for the performance of a company (Wu et al., 2014; Zamagni et al., 2011). To define the product system under study, a decision was made to choose an imaginary CRC and SRC building component without further dimensional specifications. However, the results obtained from the S-LCA will not be dependent on the FU. Accordingly, there are no reference flows defined. The CRC element consists of concrete and carbon reinforcement and the SRC element consists of concrete and steel reinforcement. The carbon reinforcement is created through the production of carbon fibers and further processing into reinforcement, just as steel is likewise created through the production of steel and further processing into steel reinforcement.

A method to develop a Type II S-LCA was created to identify causal relations of inventory indicators and midpoint impacts on the endpoint impact workers' well-being resulting from the production of a CRC and SRC building element. Furthermore, the applicability of developing the characterization factors was verified, whenever causality was found between indicators and mid-point impacts, and between the mid-point to end-point impact. By that, a qualitative description of existing causal relations along the impact pathway is made considering specific social sustainability indicators. These indicators were defined according to the S-LCA-studies found in literature (see section 2.1). The indicators were adjusted according to the goal and scope of this study. Table 2 shows all inventory, midpoint, and endpoint indicators assessed in this study. Along the UNEP SLCA-Guidelines "workers well-being" was chosen as endpoint impact. Although workers' well-being is influenced by many impacts, this study sets its focus exemplary on three midpoint impacts. Within the framework of this study, workers' well-being is defined by the midpoint impacts: Health and safety, working hours adequacy, and social security, each of which comprehended different inventory indicators. The indicators were selected following the studies from literature review as well as recommendations from experts.

Table 2
Indicator catalogue of the study.

Inventory indicators	Midpoint impact indicators (Social Subcategory)	Endpoint impact indicator
Risk prevention and protection against accidents at work (RP)	Health and safety (WHS)	Workers' well-being (WB)
Promotion of health and safety at work (PH)		
Working conditions in the context of health and safety (WC)		
Working hours by contract (WHC)	Working hours adequacy (WWH)	
Overtime working hours (OT)		
Paid rest (PR)		
Sick leave payment (SL)	Social security (WSC)	
Parental leave payment (PL)		

3.2. Data collection

For the data collection of the study, the method of a quantitative survey was chosen. While acknowledging inherit limitations such as subjectivity in the participant selection and in the responses, as well as potential biases, it enabled the collection of site-specific data. For that, a questionnaire was developed following the structure of the previously selected indicators. It was composed of 1) a free and consented confidentiality term, 2) a sociodemographic questionnaire, 3) quantitative questions for each midpoint impact, and 4) three items for each indicator (see Table A – 1). An item is a sentence or an affirmation that represents the subjective construct to be measured through the way that the respondent answers to it (Pasquali, 2000). To develop the questionnaire as standardised as possible and to avoid potential bias in the responses, the three items per indicator were elaborated based on the work of Chabrawi et al. (2024) in which 14 psychometric scales were developed to assess the multiple aspects of the concept of Decent Work (Organization IL, 1999). The instruments related to the aforementioned subcategories presented both evidence of validity based on content and based on the intern structure. Therefore, the items measuring the indicators of interest in the present study were adapted to better frame the aspect of concern and hotpots mapped by Backes and Traverso (2023). The three items relating to assessing workers' well-being were also elaborated based on existing scales related to the topic (Ajala, 2013; Azeez and Omolade, 2013; Jarden et al., 2023).

The items were answered according to a five-point Likert scale, ranging from 1 (strongly agree) to 5 (strongly disagree). The lower the scores of all items, the higher the compliance with best practices of working conditions associated with the indicators. Items 12, 34, and 35 were written in the inverted form (see table A-1). Therefore, the scores for these items were inverted to compute the final outcomes. In addition, six questions were included, asking about quantitative information such as the number of weekly working hours by contract, or weekly overtime working hours. With these six questions as well as four demographic questions, it is possible to further evaluate the contextual information of the responses. The questionnaire was provided in English and German. After the original development of the English version, the German translation was made with a focus group. This decision was made due to the fact that the questionnaire was initially shared internationally, but as the furthest reach to companies was located in Germany, an additional German questionnaire was developed.

To assess the whole product system as defined in the goal and scope definition (see Fig. 2), the questionnaire was shared separately with five different industry sectors: carbon fiber production, carbon reinforcement production, steel production, steel reinforcement production, and cement production. A link leading to the questionnaire was shared via email, to make it as easy as possible for respondents to fill out the questionnaire. However, we were aware of the possible limitation, that workers without email access were not being reached. The goal was for the questionnaire to be shared within the companies, reaching as many workers across different positions as possible.

3.3. Developing impact assessment

Descriptive statistics was performed to analyze the sample characteristics. Inferential statistics was performed to identify 1) Differences in the aforementioned indicators between the industry groups (fiber reinforcement production, steel reinforcement production, and concrete production) to check if there are any true differences between them, and 2) Assess causality within the impact pathways found in the literature. The first part was assessed using ANOVA-one way and for the second, an equation modeling was implemented to assess which items were measuring their respective indicators and the relationship between indicators, mid-point impacts, and end-point impact. Both analyses were implemented in the software JASP version 0.17.

Before running the ANOVA-one way, the assumptions related to this technique were firstly assessed. In inferential statistics, assumptions are data verifications prior to running the analysis, and it may differ depending on the type of the statistical analysis. Normality was checked using the Shapiro-Wilk test. The homogeneity assumption was assessed by the Levene test. It was run the bootstrapping (1000 re-samplings: 95 % IC BCa) to obtain higher reliability of the results and adjust the normality distribution deviations of the sample, and the group sizes, furthermore to present a 95 % confidence interval for the average differences (Haukoos and Lewis, 2005). Given the heterogeneity of variance, it was used the Welch correction and post-hoc assessment through the Games-Howell technique (Field, 2013).

Structural equation modeling pertains to a class of methodologies that seeks to represent hypotheses about the possible relationship of variables of observed data in terms of 'structural' parameters defined by a hypothesized underlying conceptual or theoretical model. It consists of two parts: 1. the structural part linking latent variables to each other via systems of simultaneous equations, based on path analysis, and 2. the measurement part which links the latent variables to observed variables (items of a scale or questionnaire), via Confirmatory Factor Analysis (CFA) (Kaplan, 2001). Thus, SEM allows to both measure certain social phenomena of interest, while it also tests the relationship among them, which ca be of causality, moderation or mediation.

It poses significant advantage over other statistical analysis, such as to multivariate regression modelinf, which is one of the closest types of analysis to SEM. Among the advantages, SEM is able to measure the error associated the components of the structural and measurement parts, while multiple regression is not robust to measurement error, assuming perfect measurement of variables. This means that multiple regression may ignore significant errors in the model, leading to statistical inaccuracies and biased results. In the same way, SEM allows for simultaneous testing of relationships, where multiple regression is limited to testing models containing a single dependent variable (Nunkoo and Ramkissoon, 2012). Although multiple regression can be used to model more than one dependent variable, it does not allow the liberty to test different directions of dependent and independent variables, feature especially convenient to the case of Impact Pathway models. Moreover, SEM has the flexibility for theory development compared to multiple regression, due to the fact that it can propose new relationships in a model that are theoretically justified while verify the fit of the data to the model (Cheng, 2001).SEM was implemented in JASP version 0.17, using the estimator Diagonally Weighted Least Squares (DWLS) robust, due to the fact that the items comprised a Likert scale of five points, being an ordinal data and usually do not meet the normality assumption. Moreover, DWLS is also more stable for different sample sizes (Finney et al., 2016). Other than multivariate normality and sample size, other major assumptions associated with structural equation modeling are: no systematic missing data, and correct model specification (Kaplan, 2001). All fields of the form and questionnaire were made mandatory, thus no missing data yielded from the sample. Regarding the model specification, $\chi 2$ (chi-squared), $\chi 2/df$ (degrees of freedom), theComparative Fit Index (CFI), Tucker-Lewis Index (TLI), and root mean square error of approximation (RMSEA) were verified. These are adjustment indices that indicate how fit or adjusted is the tested model in a given population (Chabrawi et al., 2024). According to the thresholds for interpreting the adjustment indices, the RMSEA value should be lower than 0.08, with the 90 % confidence interval not exceeding 0.10. CFI and TLI values should be higher than 0.90, but should be preferably higher than 0.95 (Brown, 2015).

The structural equation modeling sought to analyze whether: 1) the items elaborated based on other scales were explaining the corresponding indicator, and if the indicator was a measure impacting its respective subcategory; 2) the relationship between the subcategories (midpoint impact) with Workers' well-being (endpoint impact) is of causality. In total, four paths were analysed, considering the items, indicators, and the corresponding latent variable of health and safety, working hours adequacy, and social security, separately, impacting workers' well-being, with its specific items measuring the endpoint impact (Figs. 6–8). A fourth impact pathway was assessed bringing forth M1 and M3, but considering only the items that were explaining their respective indicators, hypothesizing that both impact subcategories would impact workers' well-being (Fig. 9).

4. Results

4.1. Descriptive statistics

The questionnaire was shared with over 120 companies in at least 6 different countries within the period July–November 2023. In overall, a sample size of 48 respondents was achieved, considering only people that answered the full questionnaire. Despite the sample number, the application of SEM was preceded based on the rationale introduced by Savalei (2010) (Savalei, 2010) that analysed nonnormal, incomplete and small samples and Newitt & Hancock (Nevitt and Hancock, 2004) and Rosseel (2020) (Rosseel, 2020) that attested for the use of SEM in small samples, when fit indices and other criteria are met. Looking at respondents across all industries evaluated (see Figs. 3 and 4), it can be seen that most respondents are male and working at a production site located in Germany. With 53 %, most of the respondents stated that they needed a university degree for their role/position within the organization.

Every inventory indicator was assessed with three questions (see section 3.2). In addition to that, questions were also asked to assess the midpoint and endpoint indicators directly to perform regression-based modeling later on. The average results for the inventory indicators were determined by calculating the arithmetic mean of the three corresponding questions. For that, the responses (totally agree to totally disagree) were categorized into numbers from 1 (low risk) to 5 (high risk). Responses from inverted items were assigned accordingly in reversed order. The results are shown in Fig. 5.

The inventory indicator "overtime working hours" within the category working hours impact subcategory, is the one showing the highest result on average for all questioned respondents. In this case, higher result means a higher risk of negative impact, thus this issue should be closely evaluated in further analyses. Looking at the inventory indicator

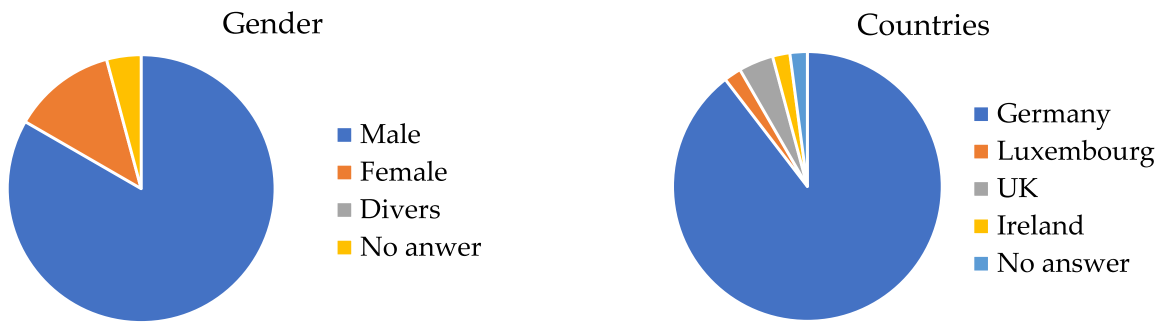

Fig. 3. Gender and Country distribution.

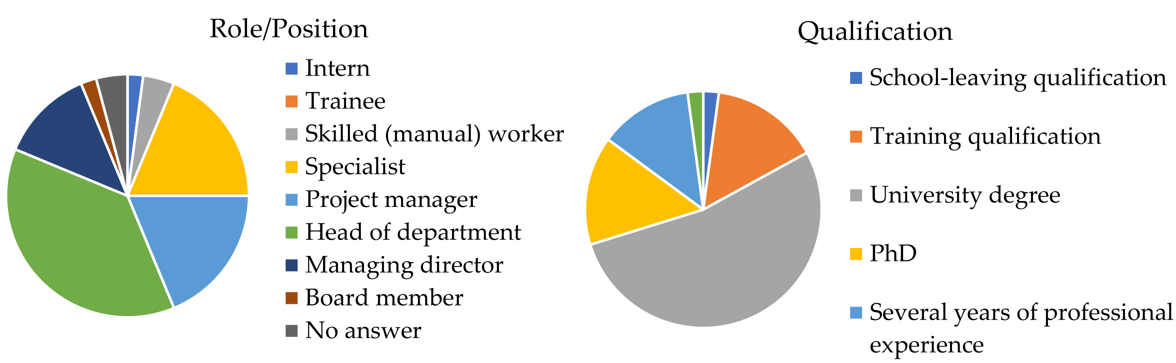

Fig. 4. Role/Position and Qualification distribution.

results for the three industries more in detail, a relatively homogenous picture becomes apparent. The results were calculated again using the arithmetic mean. For carbon reinforcement production and steel reinforcement production, respondents working in the corresponding material production as well as subsequent reinforcement production were combined due to the limited number of responses (further: fiber and steel). The arithmetic means of responses sorted by industry are shown in Table 3.

If we consider a mean ranging from 4 to 5 as a high risk of negative impact, it is possible to conclude that the result of no indicator is over this threshold, even when taking a closer look at the individual industries. The results of the endpoint impact indicator, workers' well-being, also indicate that workers responding to this study generally have well-being at their workplace. With an overall result of 1.69 for carbon reinforcement production, 1.64 for concrete production, and 1.76 for steel reinforcement production, a relatively homogenous picture is shown. For further analysing true differences among the industries' averages, inferential statistical methods were applied in the following section (see section 4.2).

Besides the items, quantitative questions were also asked intending to better understand the current state of working conditions in the construction sector. All results of these questions are shown in the appendix (see table A-2). It has been shown that with 27.1 %, the majority of the respondents indicated that, in average, they receive training at their workplace 1–2 times per year, followed by 22.9 % indicating 3–4 times. However, with 16.7 % a considerable part of the respondents still answered that, in average, they receive training at their workplace less than once a year, while 18.8 % informed to receive, in average, more than 10 times training per year. With regard to medical check-ups, 56.3 % of the respondents stated that they are offered medical check-ups in average once per year, while 39.6 % still stated, that they are offered less than that. When analysing the midpoint impact of working hours adequacy, with 60,4 %, the vast majority of respondents, informed that they work 36–40 h per week as stated in their contract. Only a small percentage of respondents answered to have a weekly working time lower than that, while 29.2 % with 41–48 h per week, have a higher working time according to their contract. More than half of the participants (52.1 %) reported to work, in average, 1–5 h overtime weekly. Even though there are also respondents (14.6 %) that indicate to work no overtime hours per week, 25 % also answered to work in average 6–10 weekly overtime hours. With regard to paid vacation days, a very homogenous picture arises with 81.3 % of respondents indicating to have 26–30 paid vacation days per year. There was no indication of less than 21 vacation days. The results on months of parental leave payment portray a very diverse picture. While 31.3 % of the respondents say that they receive 11–15 months of parental leave payment, 14.6 % indicate to have more than 20 months. Nevertheless, 25 % of the respondents gave the answer to only receive up to 5 months of parental leave payment, and 20.8 % even state not to be entitled to any month of parental leave payment.

4.2. Differences between industries

To provide an answer to the research question, what social impacts arise from the production of a CRC and an SRC building component, results from the different industries were compared to each other using the inferential statistical method ANOVA.

An ANOVA-one way was run to check differences among all indicators throughout the three industry groups, where significance was only verified only for the indicator regarding Paid rest (see Table 4). Within this analysis the assumption of normality was verified through the Shapiro-Wilk test indicating that Paid rest did not present normality for the fiber production S-W (10) = 0.817, $p < 0.001$; and concrete production S-W (26) = 0.829, $p < 0.001$; whereas it was found a normal

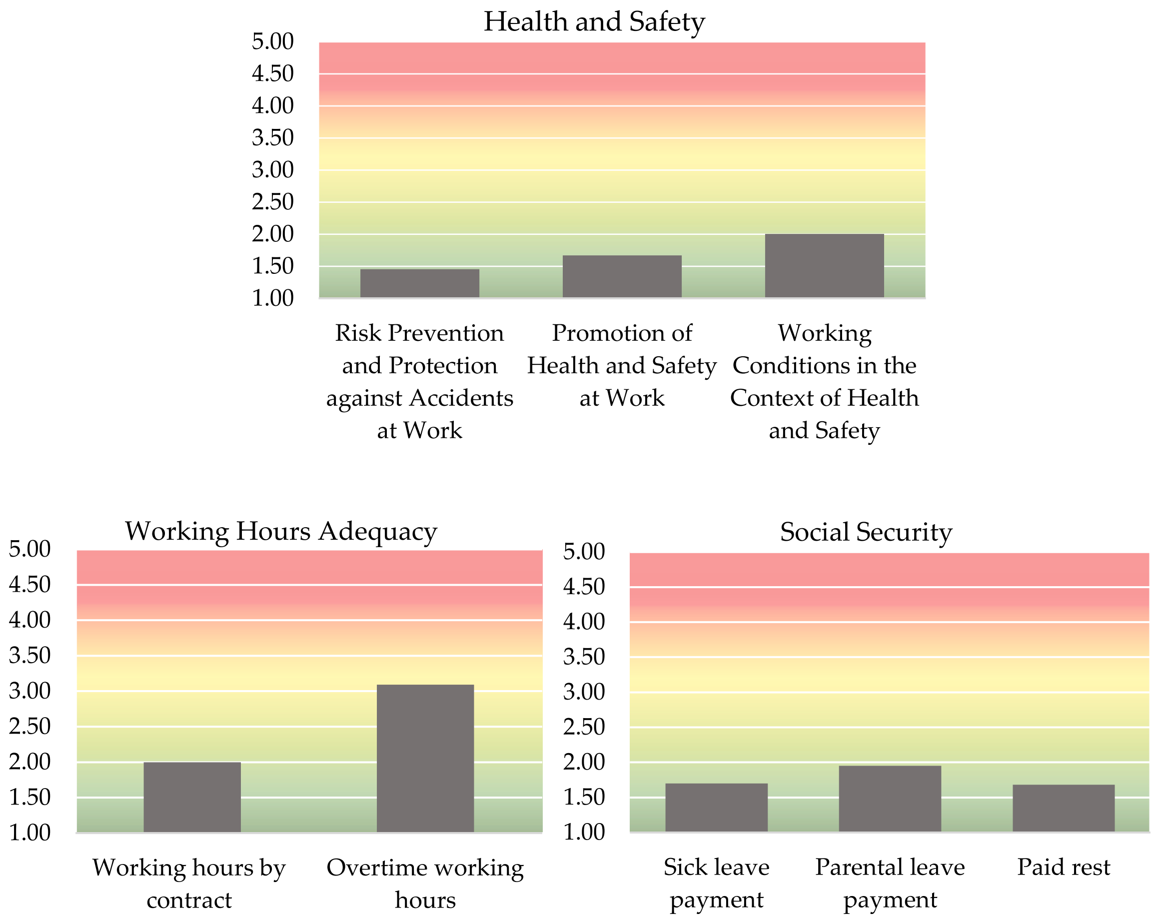

Fig. 5. Overall results of all inventory indicators in average.

Table 3
Numerical results by industry.

	Sub-category	Health and safety			Working hours adequacy		Social security		
	Inventory Indicator	Risk pre-vention and protection against accidents at work	Promo-tion of health and safety at work	Working con-ditions in the context of health and safety	Working hours by contract	Over-time working hours	Sick leave pay-ment	Parental leave pay-ment	Paid rest
Industry	Fiber	1.36	1.65	2.23	1.61	2.90	1.62	1.42	1.31
	Concrete	1.58	1.75	1.96	2.15	3.04	1.69	2.17	1.85
	Steel	1.39	1.89	1.95	1.63	3.08	1.75	1.48	1.78

Table 4
Descriptive statistics for Paid rest throughout groups.

Industry	N	Mean	Standard Deviation	Standard Error	Coefficient of variation
Fiber	10	1.283	0.352	0.111	0.274
Concrete	26	1.852	0.927	0.182	0.500
Steel	12	1.639	0.627	0.181	0.382

The ANOVA's results showed true differences among the groups [Welche's F (2,26,366) = 3.950, $p < 0.05$, Welch's $\omega^2 = 0.039$]. The post-hoc test of Games-Howell, interpreted through the bootstrapping procedure demonstrated significant differences only between the groups of fiber and concrete production, with a medium-size effect of Glass' delta = 0.6138. The comparison between the groups of fiber and steel production and concrete and steel production was not significant.

distribution for steel production S-W (12) = 0.627, p = 0.12. The homogeneity test indicated that there was no homogeneity of variance (Levene (2.45) = 8.958, $p < 0.01$).

The ANOVA's results showed true differences among the groups [Welche's F (2,26,366) = 3.950, $p < 0.05$, Welch's $\omega^2 = 0.039$]. The post-hoc test of Games-Howell, interpreted through the bootstrapping procedure demonstrated significant differences only between the groups of fiber and concrete production, with a medium-size effect of Glass' delta = 0.6138 (see Table 5). The comparison between the groups of fiber and steel production and concrete and steel production was not significant.

4.3. Social impact assessment results

Furthermore, the theoretical pathway modelled to this study still needed to be verified whether it is empirically consistent. In other words, it was checked the causality relationships between the indicators

Table 5
Post-hoc test of Games-Howell with bootstrapping (95 % IC Bca) and size effect.

Com-parison	Mean Difference	95 % CI for Mean Difference - lower	And upper	Standard error	t	Degrees of freedom	p_{tukey}	Size effect Glass' delta
Fiber - Concrete	−0.569	−1.092	−0.047	0.213	−2.671	33.988	0.030	0.6138
Fiber - Steel	−0.356	−0.899	0.187	0.212	−1.676	17.790	0.241	0.5678
Concrete - Steel	0.213	−0.418	0.845	0.256	0.831	30.660	0.687	0,3387

and midpoint impacts, and subsequently the endpoint impact: workers well-being. Since there was no significant difference found between the results of the production of a CRC and SRC building component, the industries were combined for the subsequent analysis. Moreover, it is important to notice that the small sample comprised even when adding up all the participants is a great limitation for generalizing the results yielded from it. Thus, the objective comprised in establishing a practical exercise of an impact pathway for S-LCA using inferential statistics that can be further applied in other case studies.

The first attempt of assessing the impact pathway using structural equation modeling considered all items, their respective indicators and impact subcategories (midpoint impacts), as well as workers' well-being (endpoint impact) and its correspondent items. Nevertheless, the model could not be estimated, due to the fact of having more information to be estimated than the number of information provided (degrees of freedom <0). In other words, this means that there was more information to be estimated by bringing all the variables and relationships among them to be tested, than the number of cases (respondents) from our sample. Therefore, each set of indicators and their respective impact subcategory and its relationship with the endpoint impact was assessed separately. Thus, three pathways were analysed as Model 1 (M1), Model 2 (M2), and Model 3 (M3). It is relevant to mention that the small sample was also the cause why external variables, such as sociodemographic information was not included to the models (gender, income, etc.), since a smaller number of parameters were demanded so they could be estimated based on the sample.

The three models represented the items that assessed two or three indicators, depending on the model, relating to their impact subcategory. It was assessed whether and how much each item was able to assess its corresponding indicator through CFA embedded in SEM. This also included the items that assessed the endpoint impact. In the same direction, it was evaluated through a multiple regression, also comprised in SEM, if the indicators could predict the midpoint impact, and whether or how much the latter was impacting the endpoint impact (Figs. 6–8). For simplicity of modeling the representation of the errors of the items and the latent variables were omitted. Circles represent latent variables and rectangles represent measure variables.

M1 resulted in satisfactory fit indices ($\chi^2 = 47.999$, df = 59, $\chi^2/df = 0.82$, p = 0.846, CFI = 1.00, TLI = 1.037) (see Fig. 6). RMSEA (90 % CI) = 0.00 (0.00, 0.053), suggesting the model's possible acceptability. CFA showed that the items regarding Working conditions were unable to explain this indicator (Table 6), considering the given sample to which it was applied.

Moreover, it was found that Promotion of health and safety and Working conditions could not predict Health and safety, due to a $p > 0.05$ (Table 7). Finally, it was found a significant relationship between the midpoint and endpoint impact pointing out that, when assessed

Table 6
Unstandardized and standardized coefficients for the CFA of M1.

Latent Variable	Items	B	Std. Error	p	β
Promotion of health and safety	PH1	1.000	0.000		0.896
	PH2	0.566	0.080	<0.001	0.667
	PH3	1.191	0.238	<0.001	0.939
Risk prevention	RP1	1.000	0.000		0.807
	RP2	0.958	0.259	<0.001	0.684
	RP3	1.009	0.229	<0.001	0.714
Workers' well-being	WB1	1.000	0.000		0.556
	WB2	1.545	0.474	0.001	0.917
	WB3	1.227	0.311	<0.001	0.710
Working conditions	WC1	1.000	0.000		0.037
	WC2	−15.548	73.899	0.833	−0.616
	WC3	−9.129	42.927	0.832	−0.688

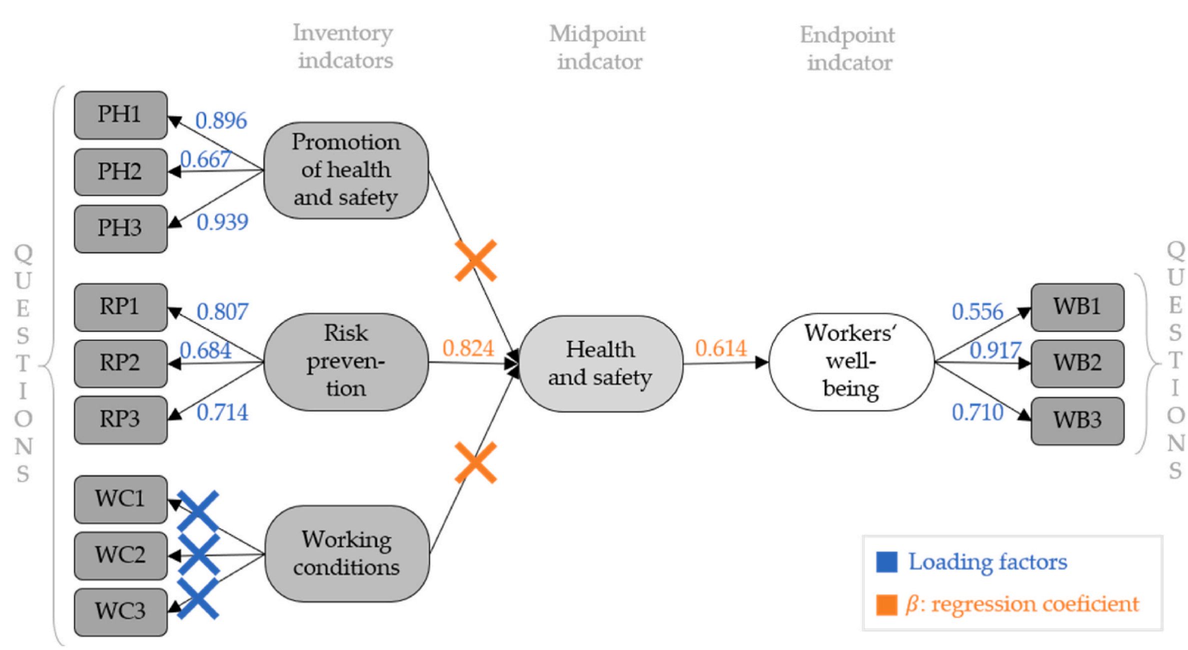

Fig. 6. M1 - Health and safety and its relation to workers' well-being.

Table 7
Results from the structure equation modeling – M1.

Predictor	Outcome	B	Std. Error	p	95 % CI: lower and upper		β
RP	WHS	0.882	0.680	0.019	−0.451	2.214	0.824
PH	WHS	−0.362	0.233	0.119	−0.818	0.094	−0.533
WC	WHS	−2.774	14.621	0.850	−31.430	25.882	−0.273
WHS	WB	0.464	0.153	0.002	0.164	0.763	0.614

separately, Health and safety impacts on the Workers' well-being (β = 0.614).

Unlike M1, M2 resulted in fairly satisfactory fit indices ($\chi^2 = 78.793$, df = 59, χ^2/df = 0.1.33, p = 0.044, CFI = 0.882, TLI = 844), RMSEA (90 % CI) = 0.084 (0.015,0.130) (see Fig. 7). The model's acceptability is inconclusive, since CFI and TLI stood roughly under the adequacy of 0.90 and the values for RMSEA were slightly higher than the expected thresholds. No adjustment indices were applied.

CFA showed that the item WCH2 regarding Working hours by contract and the item OT3 from Overtime working hours were unable to explain their following indicators (Table 8), due to a $p > 0.05$.

Although inconclusive the adjustment of M2, Table 9 shows that only Paid rest was able to predict the midpoint impact Working hours adequacy (β = 0.423). However, the midpoint impact was not a predictor of Workers' well-being, due to a $p > 0.05$.

M3 comprised the social security topic, considering the relation between the indicators with midpoint impact, and the thesis that it may impact in workers' well-being. The model obtained good fit indices ($\chi^2 = 41.790$, df = 32, χ^2/df = 1.30, p = 0.115, CFI = 0.970, TLI = 0.958), RMSEA (90 % CI) = 0.081 (0.00,0.143) (see Fig. 8). Although the upper confidence interval of RMSEA was higher than expected (0.10), it is possible to infer the model's adjustment.

The analysis of the CFA from M3 indicated that the items relating to Parental leave payment were not able to explain the phenomenon, with $p > 0.05$, according to Table 10.

Furthermore, when assessing if the indicators can predict the impact subcategory, it was observed that only Sick leave payment was significant (β = 0.843) (see Table 11). Social security was also a predictor of the endpoint impact, indicating that it influences the Workers' well-being (β = 0.767).

Finally, a fourth model converged M1 and M3, since they demonstrated good adjustment indices and at least one pathway from the measured items until the endpoint impact showed to be thoroughly significant. Thus, it was considered only the items that showed to be explaining their related indicators ($p > 0.05$), as represented in Fig. 9.

Table 8
Unstandardized and standardized coefficients for the CFA of M2.

Latent variables	Items	B	Std. Error	p	β
Overtime working hours	OT1	1.000	0.000		0.567
	OT2	0.898	0.419	0.032	0.536
	OT3	0.575	0.347	0.097	0.322
Paid rest	PR1	1.000	0.000		0.543
	PR2	2.617	1.221	0.032	0.583
	PR3	2.804	1.253	0.025	0.806
Workers' well-being	WB1	1.000	0.000		0.563
	WB2	1.621	0.542	0.003	0.974
	WB3	1.084	0.299	<0.001	0.635
Working hours by contract	WHC1	1.000	0.000		0.924
	WHC2	0.353	0.272	0.194	0.247
	WHC3	0.699	0.334	0.036	0.446

Therefore, model 4 included the three items regarding promotion of health and safety, risk prevention and sick leave payment, each. The first two are theoretically included in the Health and safety impact subcategory, whereas the last one is foreseen in the Social security scope.

M4 resulted in satisfactory fit indices ($\chi^2 = 55.902$, df = 71, χ^2/df = 0.78, p = 0.905, CFI = 1.00, TLI = 1.026), RMSEA (90 % CI) = 0.00 (0.00,0.036), indicating the possible acceptability of the model. The CFA ran for M4 indicated that all the items considered in this model explained their respective indicators (Table 12).

Finally, Table 13 shows that, within M4, Risk Prevention was almost significant (p = 0.064) as a predictor to the midpoint impact Health and Safety. When the indicators from Social Security and Health and Safety were brought together in the same model, the effect of the latter became

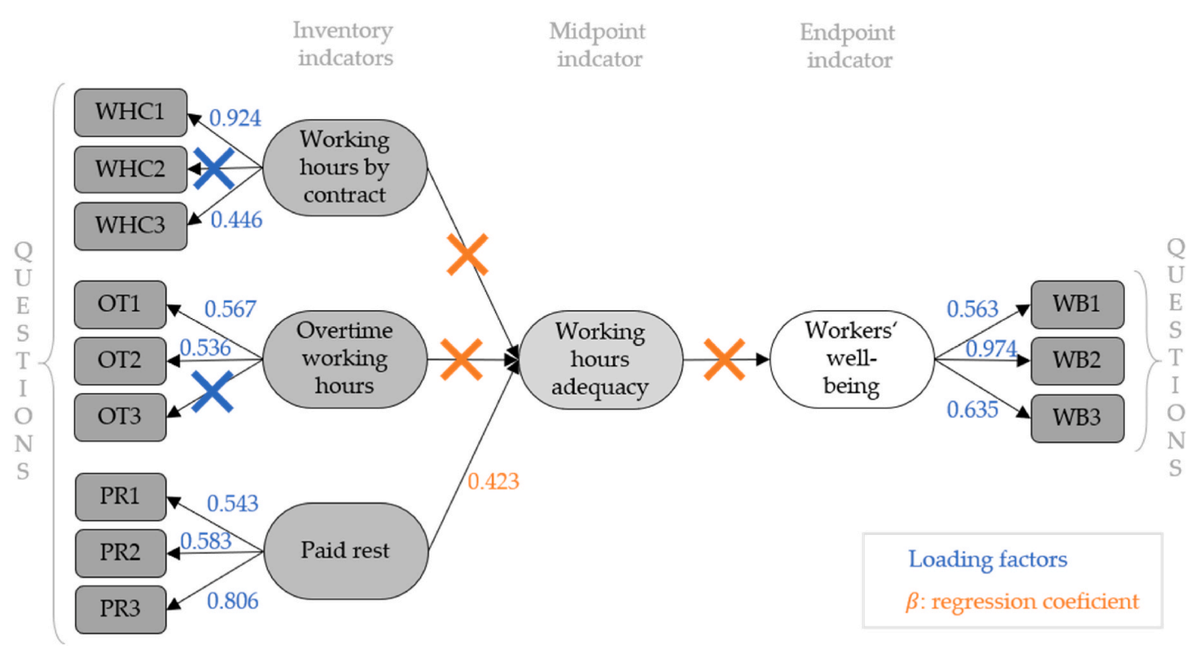

Fig. 7. M2 - Working hours adequacy and its relation to workers' well-being.

Table 9
Results from the structure equation modeling – M2.

Predictor	Outcome	B	Std. Error	p	95 % CI: lower and upper		β
WHC	WWH	0.137	0.423	0.747	−0.693	0.966	0.125
OT	WWH	0.654	0.377	0.082	−0.084	1.392	0.720
PR	WWH	1.031	0.521	0.048	0.010	2.051	0.423
WWH	WB	0.207	0.121	0.087	−0.030	0.445	0.407

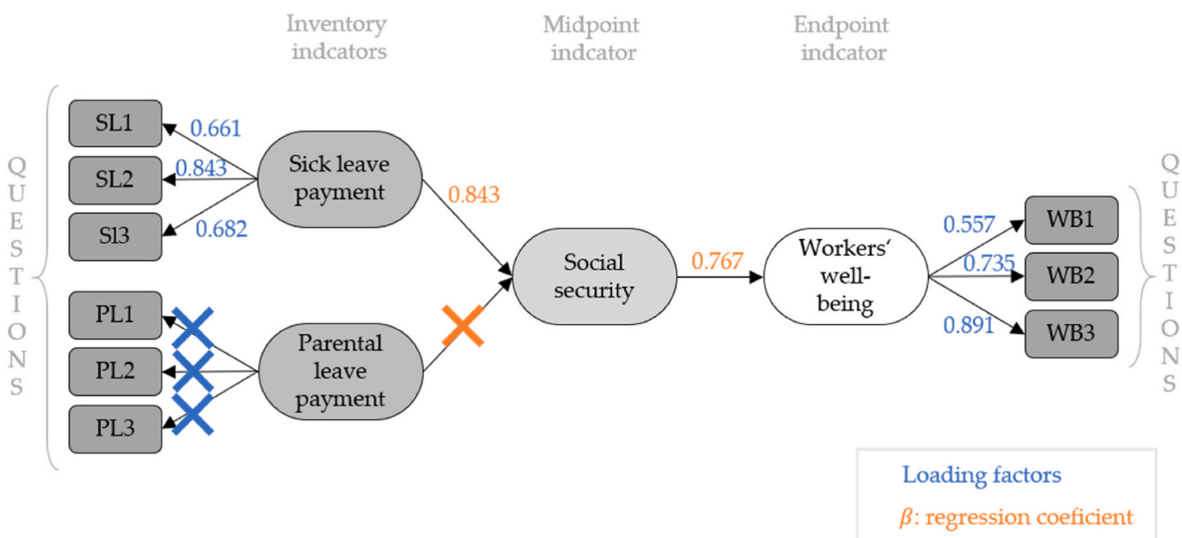

Fig. 8. M3 - Social security and its relation to workers' well-being.

Table 10
Unstandardized and standardized coefficients for the CFA of M3.

Latent variables	Items	B	Std. Error	p	β
Parental leave payment	PL1	1.000	0.000		0.642
	PL2	0.542	0.539	0.315	0.276
	PL3	1.045	0.729	0.152	0.533
Sick leave payment	SL1	1.000	0.000		0.661
	SL2	1.280	0.233	<0.001	0.843
	SL3	1.220	0.310	<0.001	0.682
Workers' well-being	WB1	1.000	0.000		0.557
	WB2	1.235	0.284	<0.001	0.735
	WB3	1.536	0.284	<0.001	0.891

non-significant, and only Social Security predicted the endpoint impact workers' well-being (β = 0.626).

4.4. Interpretation

Before the findings presented can be further interpreted, it must be clearly stated that this work is an exploratory study. Due to the small sample obtained, the SEM analyses constituted in an example on how impact pathway assessments can be well structured and verified for social science modeling schemas. Therefore, the findings related to the SEM analyses cannot be taken as a true representation of the industries' realities with regards to the working conditions assessed hereto. Nevertheless, the method proposed is of crucial importance, as much as no study of this kind could be found in the literature, and the social sustainability of a CRC building component so far has never been analysed in accordance with the UNEP Guidelines. Three pathways were separately analysed, different from the one converging them altogether due to the restriction of degrees of freedom to estimate all the parameters. Although all indicators and impact (sub)categories were carefully selected based on a detailed literature review, the possibility that negative social impacts could exist in other stakeholder categories and other midpoint impacts cannot be ruled out. In addition, to avoid biases and diminish the error in the measurements, improving the overall validity of the indicators assessment, the questionnaire was based on the work of Chabrawi, who developed 14 different scales using the psychometric procedures (Pasquali, 2000) for objectively assessing objective measures (Chabrawi et al., 2024). It is also important to notice that the hotspots assessed are related to the whole value chain of the selected industries. Therefore, illiterate workers of the German or English language could not be reached with the questionnaire, as it was only sent out in these two languages. While the sample size of 48 workers in the construction industry limits the representativeness and the generalization of the findings, the insights gained here are still of the highest importance in a first attempt toward advancing social sustainability assessments in the construction sector. Having established that, the question can now be asked: what do the findings mean concretely for sustainability assessments in the construction industry, and particularly for CRC and SRC building components?

As the descriptive analysis of the results has shown, in overall, this sample of respondents generally showed a high level of satisfaction for

Table 11
Results from the structure equation modeling – M3.

Predictor	Outcome	B	Std. Error	p	95 % CI: lower and upper		β
SL	WSC	1.002	0.186	<0.001	0.637	1.366	0.843
PL	WSC	−0.065	0.203	0.750	−0.463	0.334	−0.064
WSC	WB	0.460	0.127	<0.001	0.211	0.709	0.767

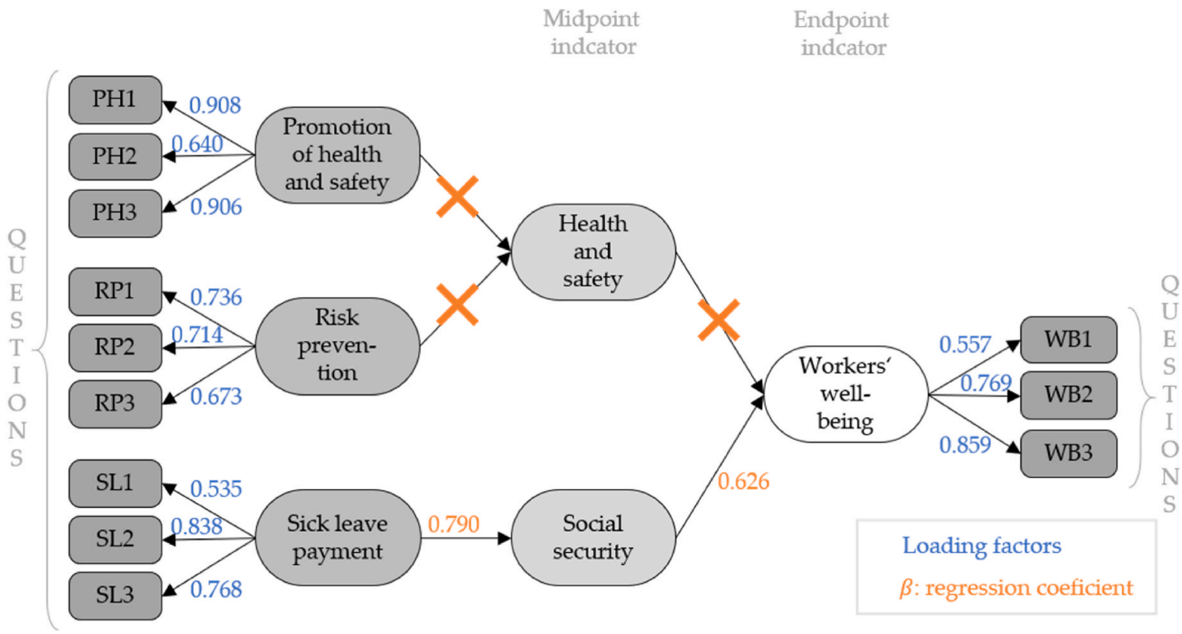

Fig. 9. M4 - Health and safety, social security and their combined relationship to workers' well-being.

Table 12
Unstandardized and standardized coefficients for the CFA of M4.

Latent variables	Items	B	Std. Error	p	β
Promotion of health and safety	PH1	1.000	0.000		0.908
	PH2	0.705	0.113	<0.001	0.640
	PH3	0.997	0.205	<0.001	0.906
Risk prevention	RP1	1.000	0.000		0.736
	RP2	0.970	0.188	<0.001	0.714
	RP3	0.915	0.195	<0.001	0.673
Sick leave payment	SL1	1.000	0.000		0.535
	SL2	1.564	0.383	<0.001	0.838
	SL3	1.435	0.404	<0.001	0.768
Workers' well-being	WB1	1.000	0.000		0.557
	WB2	1.380	0.350	<0.001	0.769
	WB3	1.542	0.273	<0.001	0.859

the indicators assessed. Only the inventory indicator regarding overtime working hours showed higher potential negative effect. The analyses of the quantitative questions provided some very interesting and complementary findings. It could clearly be seen that within this sample size, it is not common for respondents to work only part-time, or with a reduced amount of weekly working hours according to their contract. Regarding overtime, the majority of respondents indicated not to work more than 10 h overtime per week. However, 58.3 % of all respondents stated that they strongly disagree or disagree, to the item "I get paid overtime". This means, that even though the numbers of weekly overtime do not seem to be very high, the majority of workers are still not getting paid for these overtime working hours. And even though 62.5 % of respondents stated that they strongly agree or agree to the item "It is possible to work extra hours for a few days in order to take a day off later on", only 25 % still strongly disagree or disagree to that. With regard to paid rest, according to the Federal Leave Law of Germany, employees are entitled to, at least, 24 working days' paid leave per year (Bundesurlaubsgesetz: BUrlG, 1963). Since 91.7 % of the respondents stated to work in Germany, this is in line with the results that a vast majority of respondents indicated to have 26–30 paid vacation days per year. Concerning parental leave payment, a different picture arises. The website of the Federal Ministry for Family Affairs, Senior Citizens, Women, and Youth states that parents in Germany are jointly entitled to up to 24 months of paid parental leave. The employer's consent is not required (Bundesministerium für Familie, 2021). Nevertheless, only 14.6 % of respondents stated to be entitled to more than 20 months of paid parental leave payment. The fact that over 20 % indicated not to be entitled to any parental leave payment is even more surprising. A potential explanation for this could be that the workers might not be aware of their right to receive parental leave payment.

Following the descriptive analysis of the results, inferential statistics were made use of, to examine possible differences between the indicators among the studied industries, and for checking the existence of causal relations that were theoretically predicted, based on the literature review, between the social indicators and the respective aforementioned impacts. The ANOVAs run showed no significant difference between the steel and carbon reinforcement production. Therefore, it can be concluded that within the framework of this study, and for the restricted population analysed, the production of a CRC element is not significantly more or less socially sustainable than the one of an SRC element. The only significant difference that could be found was in the results of social impacts within carbon reinforcement production and concrete production for the inventory indicator paid rest. The size effect was considered medium, with a calculated Glass' delta of 0.6138, between the two industries. This means that within the carbon reinforcement production, paid rest was assessed in a more satisfactory way, with

Table 13
Results from the structure equation modeling – M4.

Predictor	Outcome	B	Std. Error	p	95 % CI: lower and upper		β
SL	WSC	1.387	0.260	<0.001	0.878	1.896	0.790
RP	WHS	3.074	1.659	0.064	−0.177	6.326	2.262
PH	WHS	−1.950	1.318	0.139	−4.534	0.633	−1.772
WHS	WB	0.097	0.094	0.303	−0.088	0.282	0.174
WSC	WB	0.371	0.119	0.002	0.137	0.605	0.626

61,38 % of difference in relation to concrete production. On the other hand, when analysing the exploratory results of the structural equation modelling (Fig. 7), the midpoint impact working hours adequacy, to which paid rest is linked to, is not predicting the endpoint impact workers well-being. In general, the examples of the attempts on analysing causality in the assigned pathways indicated that most of the theoretical relations could not be empirically proved. The analysis of the pathways separately, showed that health and safety (Fig. 6) is only explained by the items relating to the indicator risk prevention, while also predicting the workers' well-being. Working hours adequacy on the other hand is, as mentioned before, only explained by paid rest, while it is not predicting workers well-being. It is especially interesting to verify that the inventory indicator overtime working hours as showing the highest potential negative social score in descriptive results but does not have a causal effect on the perception of working hours adequacy and the subsequent workers' well-being. Although the results from SEM cannot be taken as a representation of the sectors reality, a possible conclusion drawn from the results is that even though many of the respondents have a high risk of working overtime, this does not affect their perception of an inadequate working hours or their own well-being as workers. This could indicate that a high workload in the form of overtime above the contractually agreed time is considered normal to this sample, not directly affecting the well-being of the employees. However, this does not rule out the possibility of long-term health consequences. With regards to the pathway focusing on social security topics (Fig. 8), the midpoint impact appeared to be predicted only by sick leave payment, and not parental leave payment, while also social security was a strong predictor of workers well-being. Keeping in mind that more than 20 % stated not to be entitled to receive any parental leave payment, it is interesting to notice that this does not seem to affect the respondent's perception of having social security and furthermore well-being at their workplace.

After disregarding all inventory indicators that presented a $p > 0.05$, i.e., have shown by the CFA to not be explained by its items, another SEM was run (Fig. 9), considering the full theoretically designed model, but considering only the indicators which items were significant. It was possible to observe that health and safety, which did present a causal relationship to the workers' well-being, when analysing the pathway separately (Fig. 6), now did not show this link anymore. The midpoint impact social security, on the other hand, kept predicting the endpoint impact. When brought together to the impact pathway analysis, social security demonstrated to influence the effect of health and safety, when verifying their joint effect on workers' well-being. This shows that midpoint impact indicators are influencing each other, where social security can be potentially moderating or mediating the effect of health and safety on the workers' well-being. This does not only underline the particularly high relevance of social security for the sample of this study but especially that the variables included in a study framework can majorly influence impact pathway results. If characterization factors had been derived from the separated models, they would hinder the combined effect of the social indicators and the joint effect of midpoint impacts in the endpoint one. Given the comparative analysis from the pathways separately and the different indicators of the two impact subcategories (social security and health and safety), it becomes clear that social matters are intrinsically dynamic and context dependent, being far distant the possibility of developing characterization factors for social impact pathways, as they are used in environmental life cycle assessment. The approach of evaluating social aspects based on its sector- or product-specific context can therefore be confirmed on the basis of the available data. This raises the broader question of the extent to which social standards and benchmarks can be defined and established on the basis of impact pathways. Such regulations would significantly simplify the integration of social aspects into decision-making processes in the construction sector. However, based on the results of this study, the question arises as to whether complex social realities can be captured in generally applicable rules.

Overall, the results of this study have shown the potential of using SEM for impact pathway development. This opens up the opportunity for future application of S-LCAs using the impact pathway approach. By that, decision making based on social considerations such as workers well-being would be enhanced. Institutional sustainability goals such as the Sustainable Development Goals (SDGs), with SDG 8: decent work and economic growth, SDG 11: Sustainable cities and communities, and SDG 10: Reduced inequalities, could thereby be fostered (United Nations THE 17 GOALS). However, in addition to the opportunities offered by using SEM for impact pathway development, the study also revealed challenges. While a high level of expertise and effort is required to develop impact pathways with SEM based on primary data, the results of this study show that social aspects are not generalisable across the board. Accordingly, a thorough evaluation is needed to reliably determine the social impacts associated with a sector or a product, and it is crucial that further efforts be made to develop the methods to this end by both research and industry.

5. Conclusion

To summarize the study, we developed a new method to perform a type II S-LCA (impact pathway) along the UNEP Guidelines from 2020 (Level(s): Putting circularity into practice, 2021). For a case study on CRC and SRC, site-specific data were gathered to determine the social impacts on workers arising from the production of a CRC and an SRC building component. For that, 48 people working in the respective sectors within the European construction industry were questioned with an online survey. Descriptive statistics, as well as inferential statistical methods including ANOVA and SEM were used for the assessment of the results. This work is an explorative study, which performed a very first-time impact pathway for the production of CRC and SRC building components. Literature review revealed previous Type I S-LCAs, however, none of them used a comparative approach for the production of CRC and SRC building components. The results obtained with this study are an initial contribution and an important step forward in the establishment of type II S-LCAs as well as driving sustainable development in the construction sector, and for S-LCA as a whole. Following main outcomes could be established.

- ANOVAs revealed that there were no differences in the average of the responses provided by the group or participants from the CRC and SRC sectors;
- Overtime working hours has a high potential negative effect on workers, whereas there was no causal relation to workers' well-being found. In other words, working overtime hours do not appear to influence the perceived well-being of the workers from the studied sample;
- The same could be observed for the results of parental leave payment.
- Structural equation modelling showed that the indicator explaining social security was sick leave payment, and this midpoint impact was found as a major predictor of workers' well-being, in relation to the other pathways.
- The analysis of the pathway related to health and safety separately and combined with social security have shown how interactive and dynamic a social phenomenon can be. Thus, an indicator or a midpoint impact has not always the same impact on the midpoint or endpoint impact, being context dependent, and surely depending on the studied sample. Therefore, the possible attribution of a characterization factor in S-LCA should vary according to the model designed. Social sustainability impacts do not cause separate effects in impact pathways but influence each other across the different variables that a social phenomenon may encompass.

Answering the research question and whether there are differences in social impacts arising from the production of a CRC and SRC building component, the product system and sample assessed in this study showed no substantiated differences. A social factor of prominent relevance was found in the analysed sample for the production of reinforced concrete. Thus, a special focus needs to be placed on social security, especially with regards to sick leave payment, within the production sector of reinforced concrete. This indicator and its subsequent social subcategory shown to highly influence the well-being perception of the workers. Additionally, the current situation of overtime working hours must be improved. Even though there was no causal relation to the workers' well-being found within the sample of this study, it showed the highest potential of a negative social impact. The reason why the link between working hours and workers' well-being was not significant may also be due to the small sample size, and a larger population could have shown an indirect effect between them. Nevertheless, cultural factors should always be considered, as in some contexts over working can be also seen as a badge of honour. Therefore, further research should be conducted by applying the approach to a lager sample size to confirm and/or amend the results obtained in this study. Future research should also address the question of the extent to which the results of an impact pathway with SEM can be incorporated into sustainability standards and requirements in the construction sector. As this study has shown, a holistic evaluation and generalisation of social impacts is highly complex. The use of SEM for impact pathway development shows a promising approach, yet due to the inherent limitations of this study, it remains to be validated on a larger sample. Further efforts are necessary to advance the development of type II S-LCA methods to comprehensively assess social impacts in the future and integrate them into decision-making processes.

CRediT authorship contribution statement

Alexandra Weniger: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **Arij Mohamad Radwan Omar Chabrawi:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis. **Marzia Traverso:** Writing – review & editing, Supervision, Funding acquisition.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Table A - 1 Questionnaire

#	Question	Inventory Indicator	Midpoint Impact	Endpoint Impact
1	I have well-being at my workplace			Workers well-being
2	I find real enjoyment in my work			
3	I feel satisfied with my job			
4	My job provides me with the conditions for having well-being			
5	I feel healthy and safe at my workplace		Health and safety	
6	The organisation requires workers to comply with all the regulations relating to the prevention of risks and the protection of their health at work	Risk prevention and protection against accidents at work		
7	The organisation takes the necessary precautions to protect workers from dangerous substances			
8	The organisation regularly monitors accidents and risks to improve safety measures at work			
9	There is an emergency plan focused on prevention, training and response to emergency situations	Promotion of health and safety at work		
10	The organisation continually runs training and revision courses on topics related to workers' health and safety			
11	The organisation offers specialised care to workers who have suffered work-related illnesses or accidents and are undergoing rehabilitation at work			
12	In my work, I have to regularly handle hazardous substances/machinery	Working conditions in the context of health and safety		
13	If I have to handle dangerous products or machinery, I will receive training from the organisation to ensure my health and safety			
14	The organisation provides the material resources necessary to carry out my work			
15	How often do you receive training at your workplace in average per year?			
16	How often are you offered medical check-ups at your workplace in average per year?			
17	My working hours are consistent with my contract and comply with the laws of the country in which I work		Working hours adequacy	
18	I have flexibility in my work, and can take time off for holidays for personal reasons	Working hours by contract		
19	I can decide when to take a break during my workday			
20	The number of working hours is negotiated in a fair and objective way according to the workload			
21	I work more hours than stated in my contract or employment agreement	Overtime working hours		
22	It is possible to work extra hours for a few days in order to take a day off later on			
23	I get paid overtime			
24	I get my standard monthly payment when I'm on vacation	Paid rest		
25	My weekly off-days are paid			
26	I have the right to choose which day(s) I take off for personal reasons			

(*continued on next page*)

(*continued*)

#	Question	Inventory Indicator	Midpoint Impact	Endpoint Impact
27	How many hours do you work by contract per week?			
28	How many hours do you work in average overtime per week?			
29	The organization I work for provides me with social security		Social security	
30	I am entitled to sick leave payment	Sick leave payment		
31	I will receive financial assistance if I need to take time off work due to a work-related accident			
32	I have a right to a compensation if I have a chronic illness related to work			
33	I am entitled to receive parental leave payment	Parental leave payment		
34	Employees have to work during parental leave			
35	Employees that take parental leave have disadvantages at work			
36	How many vacation days do you have per year?			
37	For how long are you entitled to receive parental leave payment?			
38	What Gender do you identify yourself with?			
39	What is your role within the organization you work for?			
40	What degree is required for your role within the organization you work for?			
41	In which country is your workplace located?			

Table A - 2 Results of the quantitative questions (numerical and in percentage)

Training per year	<1	1–2	3–4	5–6	7–8	9–10	>10	
	8	13	11	6	1	0	9	
	16,7 %	27,1 %	22,9 %	12,5 %	2,1 %	0,0 %	18,8 %	
Medical check-ups per year	**<1**	**1–2**	**3–4**	**5–6**	**7–8**	**9–10**	**>10**	
	19	27	1	0	0	1	0	
	39,6 %	56,3 %	2,1 %	0,0 %	0,0 %	2,1 %	0,0 %	
Hours by contract per week	**<20**	**20–25**	**26–30**	**31–35**	**36–40**	**41–48**	**>48**	
	0	1	1	2	29	14	1	
	0,0 %	2,1 %	2,1 %	4,2 %	60,4 %	29,2 %	2,1 %	
Overtime working hours per week	**0**	**1–5**	**6–10**	**11–15**	**16–20**	**21–25**	**26–30**	**>30**
	7	25	12	2	1	0	0	1
	14,6 %	52,1 %	25,0 %	4,2 %	2,1 %	0,0 %	0,0 %	2,1 %
Vacation days per year	**<10**	**10–15**	**16–20**	**21–25**	**26–30**	**31–35**	**>35**	
	0	0	0	2	39	3	4	
	0,0 %	0,0 %	0,0 %	4,2 %	81,3 %	6,3 %	8,3 %	
Months of parental leave payment	**None**	**up to 5 months**	**5–10 months**	**11–15 months**	**16–20 months**	**>20 months**		
	10	12	3	15	1	7		
	20,8 %	25,0 %	6,3 %	31,3 %	2,1 %	14,6 %		

Data availability

The authors do not have permission to share data.

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