Extended Abstract

Development of an Excel toolkit for checking composite steel and concrete beams

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Abstract

The main goal of this work is to develop a toolkit in Excel to verify composite steel and concrete beams with solid slabs and non-encased profiles, based in Eurocode 4. As such, in first place the normative contextualization is presented, where some particularities of this type of construction are illustrated; then the toolkit itself is explained, with an applied example to demonstrate the functionality; and, finally, a parametric analysis is made with the toolkit developed.

Parallelly, it is aimed to introduce the concept of Building Information Modeling. To do so, the concept is approached, doing a comparison to the actual situation; it is presented some problems that are intended to solve with this new methodology, where some transversal advantages for the many intervenient in a project are exhibit; the diverse dimensions and possibilities of this approach are shown; some problems and challenges in the journey to adopt this new concept are identified; and is exemplified, thru some Revit models, the modeling in BIM environment, doing a parallelism to the initial goal of this work.

Keywords: Composite Beam, Eurocode 4, Excel toolkit, Building Information Modeling, BIM

1. Introduction

The main objective of this thesis is to develop a toolkit that can verify the Ultimate Limit States of composite steel and concrete beams, in accordance to Eurocode 4. Also, it's intended to perform an analysis to different parameters to check the behavior of different solutions.

The second objective is to address a topic that is relatively new in the industry sector, and clarify what is it, problems that it may solve, some conceptual dimensions, challenges to the adoption and, in the end, exemplify some models related to the main objective.

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2. Composite Construction

2.1. Concept

The idea of composite concrete and steel construction consists in combining different materials, each one with his own properties, to form a cross-section that is more resistant. In this case, the good behavior on compression from concrete is combined with the efficiency from the structural steel on traction. To ensure the shear connection between materials, a shear connector is used.

This kind of construction exhibit various advantages over traditional methods, namely increased velocity and simplicity in construction, flexibility for future modifications and great value for rehabilitation of existent constructions.

2.2. Examples

Some examples of this type of construction are shown below. The first example (Illustration 2.1a) is a building in Lisbon, which has a beam system in HEB160 steel profiles with welded headed stud connectors. The second case is a tower in New York that has composite floors as well as composite beams (Illustration 2.1b). The last example is an elevated parking lot in Les Milles, France; that is a bit different from the previous ones by its nature (Illustration 2.1c).

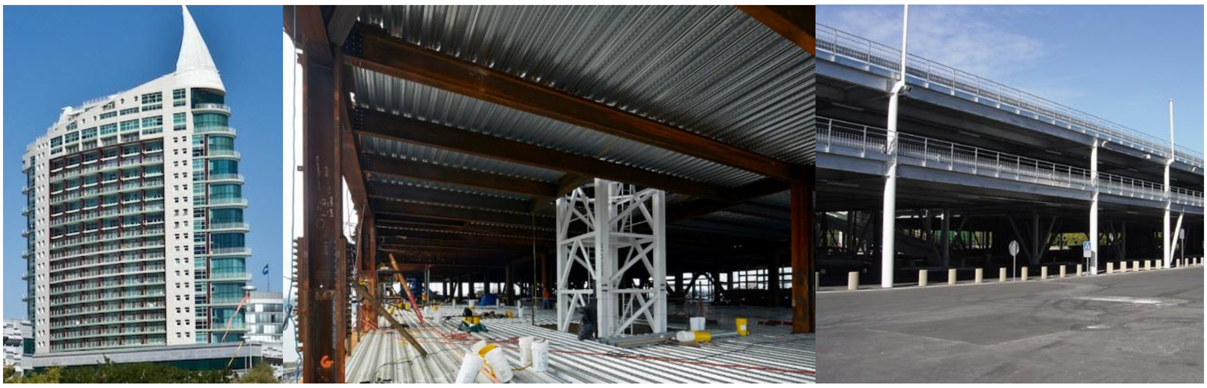

ILLUSTRATION 2.1 – EXAMPLES OF COMPOSITE STEEL AND CONCRETE CONSTRUCTION – A)S.GABRIEL TOWER; B)HUDSON YARDS; C)CARREFOUR HYPERMARKET AIX

The objective of this illustrations is to show a different applicability for this kind of construction, in diverse environments and with different purposes.

3. Building Information Modeling

3.1. Definition

This new approach reflects a change in the paradigm of the construction industry, specifically at the level of design and documentation. All the information is stored in a big data base, and consists of parameterized and interconnected information, where a change in the input is reflected across the project. The data can then be used to evaluate design choices, measure energetic performance, calculate costs, produce high quality drawings and plan construction.

Another aspect is the coordination between different specialties, as one model can integrate the information from them all. This allows an increase in efficiency and effectiveness on error or incompatibilities detection, that otherwise would only be spotted as construction proceeds. With this it’s expected to decrease the costs associated with late design changes and improve productivity on the construction sector.

3.2. Problems to be solved

Traditional construction methods can’t handle the present pressure from the increasing project complexities, shorter deadlines and greater demand for sustainable solutions; while reducing costs and materials usage. The next scheme (Illustration 3.1) shows different aspects that may be solved with a new methodology.

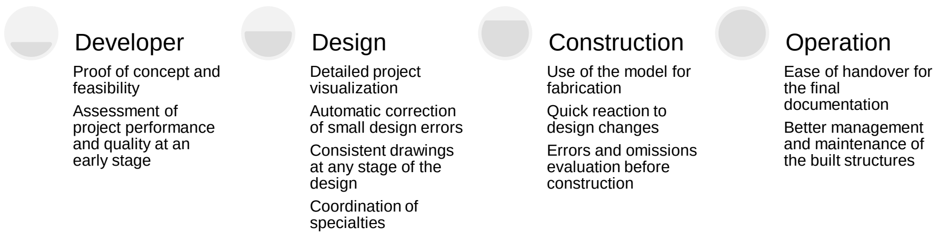

ILLUSTRATION 3.1 – PROBLEMS THAT BIM AIMS TO MITIGATE

3.3. BIM dimensions and possibilities

This methodology is characterized as multidimensional and multidisciplinary. Besides modeling the entire project in 3D, the model includes additional information on materials costs, time planning abilities, energy evaluation capabilities and possibility for lifetime analysis. The next illustration (Illustration 3.2) displays the different dimensions of this methodology.

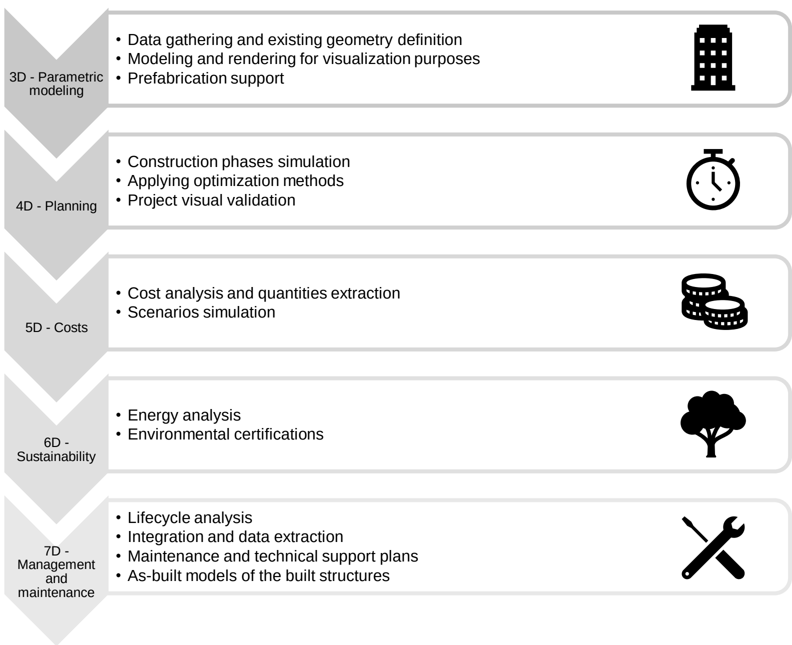

ILLUSTRATION 3.2 – CONCEPTUAL DIMENSIONS OF BIM

The capability to influence working safety decreases over time, thus accident prevention through design could be made and this would be the eighth dimension.

3.4. Difficulties and challenges of a new methodology

A change in paradigm is not easy to implement. Some problems will arise due to changes in work relations, transformation of workflows and legal limitations. To accomplish this, it's necessary to define rules for sharing information between different stakeholders; change the legal legislation to accommodate the new way of working; it's imperative to teach people the new methodology; and update the technological equipment so it can handle the tools needed.

3.5. Modeling examples

Nawari e Kuenstle (2015) give the theory behind the tools used for modeling the studied examples. The first consists on a headed shear stud, modelled as a family of "Structural Connections" accordingly to the ISO 13918-2008 (ISO, 2008), and the workflow used is described below:

i. Plan and make a draft of the geometry, as well as the parameters and views necessary;
ii. Create a new file through a template within the right category;
iii. Define the multiple views needed and tag them;
iv. Identify clearly where is the origin and insert point for the model;
v. Trace the reference planes and lines necessary for drawing the geometry;
vi. Model the geometry and components;
vii. Dimension the multiple elements to correctly parameterize de model;
viii. Tag the dimensions created as "type" or "instance" parameters;
ix. Vary the parameters and check for errors;
x. Save different "types" of the same family by changing the parameters.

The result of the exercise using the workflow above is shown next (Illustration 3.3).

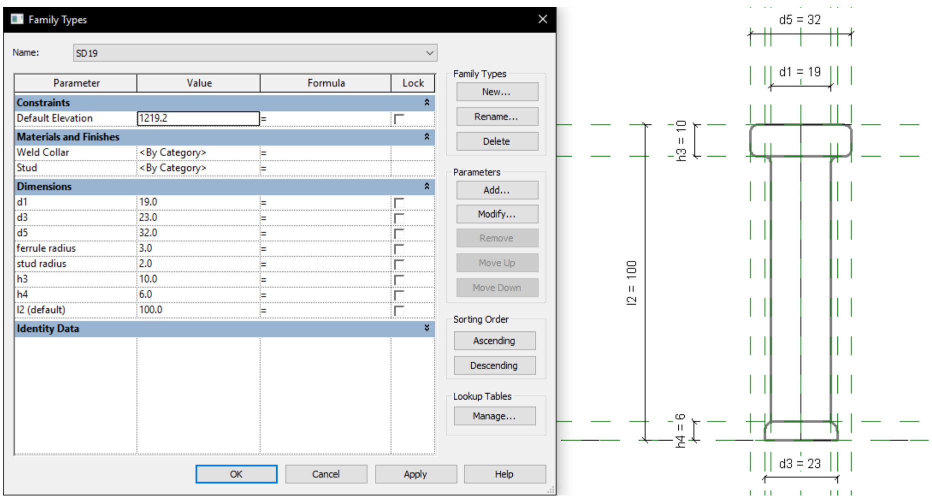

ILLUSTRATION 3.3 – MODEL CREATED AND CORRESPONDENT PARAMETERS

The second example is a family of an unequal flange beam. The methodology used is the same as before, only changing the type to "Structural Framing", and Illustration 3.4 shows the result.

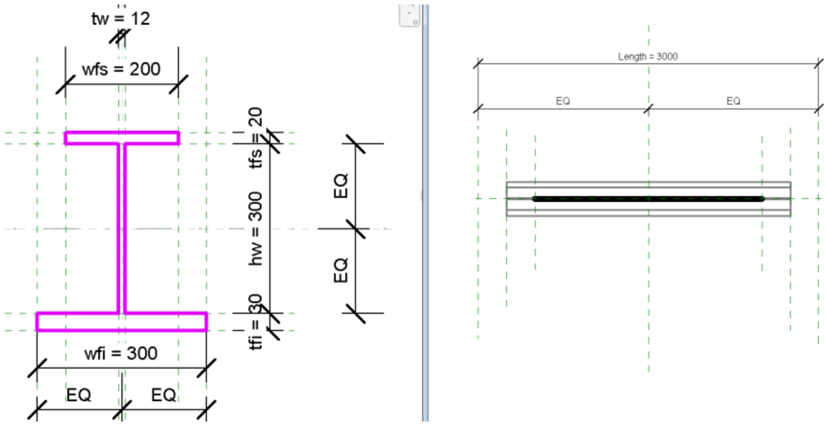

ILLUSTRATION 3.4 – REPRESENTATION OF AN UNEQUAL FLANGE BEAM

Both examples where later used to illustrate the various cases studied in the next chapters.

4. Ultimate Limit States

4.1. Regulation

The design must ensure the safety e functionality for the structure being designed. In Portugal, this information is scattered in multiple documents, namely “RSA – Regulamento de Segurança e Ações”, “REBAP – Regulamento de Estruturas de Betão Armado e Pré-esforçado” e “REAE – Regulamento de Estruturas de Aço para Edifícios”; the Eurocode join everything in a series of documents that allow for an increase of knowledge in areas such as composite, timber and aluminum structures. Although this Europeen standard has no force of law yet, it was chosen as the base for the work.

The relevant standards are the EN 1990, EN 1991-1-1, EN 1994-1-1 and some parts of EN1992-1-1 and EN1993-1-1. As already stated, the ISO 13918 is used for referring shear connector properties.

4.2. Resistance of cross-sections

There are some considerations to make before evaluating the resistant moment. First, we should get the effective widths in accordance to 5.4.1.2 (CEN, 2004). Next, it’s necessary to classify the section in as seen in 5.5.2 (CEN, 2005). In some cases, can be used the method of “web hole” from 6.2.2.4 (CEN, 2005). Plastic analysis was used for the evaluation of resistant moments, as seen in 6.2.1 and 6.2.2 (CEN, 2004).

4.3. Member and global verifications

To evaluate the safety of continuous beams some considerations should be made regarding lateral buckling, concrete cracking, shear connectors and transverse reinforcement. Also, the type of global analysis used was the elastic linear without cracking of concrete and then, in case of cracking, was applied a redistribution to account for the effect, like on 5.4.4 (CEN, 2004). Effects from actions were evaluated using the Cross method using a non-cracked inertia for the beam rigidity.

For optimizing the bending moment diagram, a redistribution may be used in case of not having lateral torsional buckling effects. Those effects may be evaluated by 6.4.2 (CEN, 2004) and imply the calculation of an elastic critical moment (Johnson, 1994).

To ensure the verification of longitudinal shear connection, the beam must have an adequate number of headed stud connectors that satisfy 6.6.3 (CEN, 2004); and other considerations should also be compliant, namely 6.6.1.2 and 6.6.1.3 (CEN, 2004). Regarding transverse reinforcement, the specifications may be seen in 6.6.6 (CEN, 2004). Finally, some construction detailing must be verified, as seen in 6.6.5 (CEN, 2004).

5. Parametric Analysis

5.1. Toolkit

To speed up design, engineers create toolkits that also help them achieve better results. In this work, it was created an Excel toolkit which can evaluate the Ultimate Limit State for a two-span continuous beam, of an uncased cross-section with a solid slab.

As described before, it some examples were created to show some capabilities of BIM (Illustration 5.1). Those only refer to the modeling capabilities of Revit, a software that works with this new methodology.

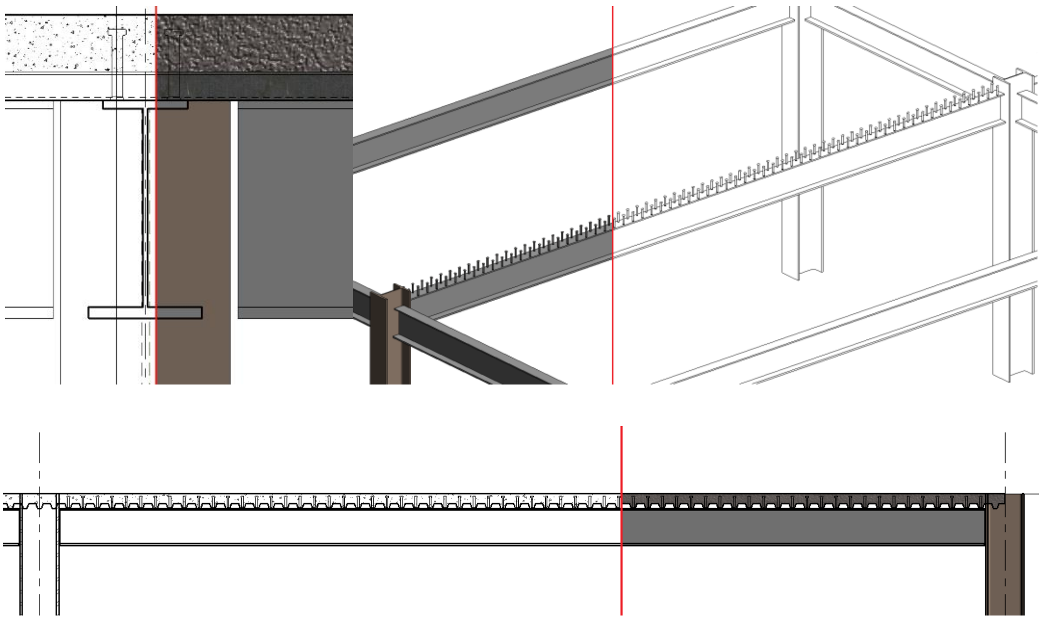

ILLUSTRATION 5.1 – EXAMPLES OF MODELING IN REVIT

Although not impossible, the toolkit and the BIM program were not connected and, therefore, after running the analysis the parameters for the beam had to be manually inserted in Revit.

5.2. Results

It was conducted an analysis to a two-span beam to evaluate the effects of concrete type, structural steel type, shear connection degree, slab height and relation between span length.

For the transverse reinforcement, it was made clear that smaller spans are more demanding, and the cause is the increase in longitudinal force due to the decrease in connectors spacing. Another important factor is the shear connection degree, where smaller degrees lead to a decrease in the need for transverse reinforcement. This can be explained by the smaller longitudinal force in smaller resistant moments. Finally, smaller sized profiles have less problems to verify the transverse reinforcement, as they have less capacity to mobilize longitudinal shear (Illustration 5.2).

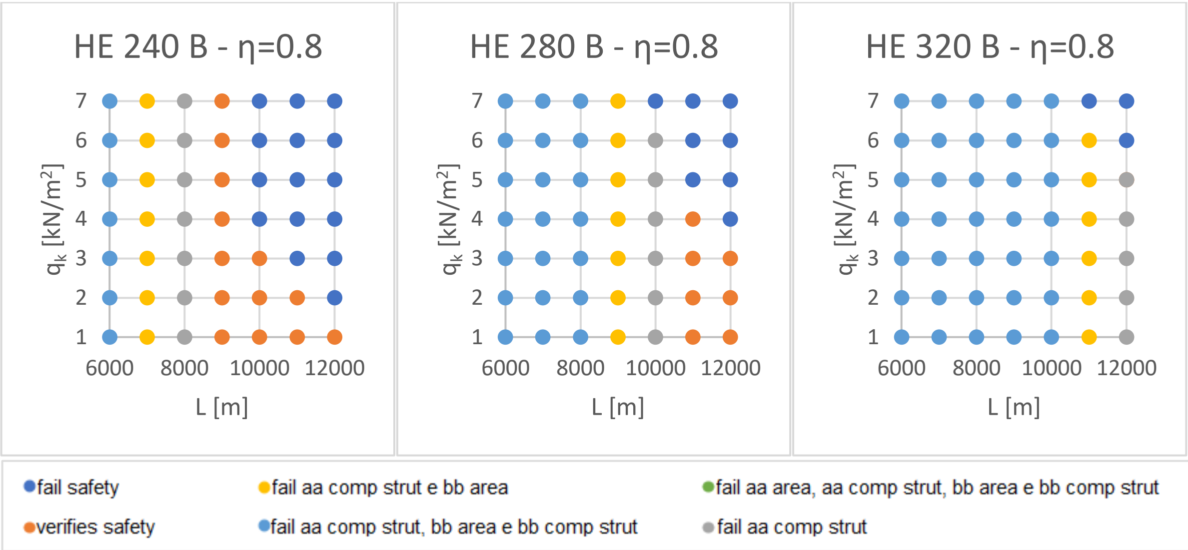

ILLUSTRATION 5.2 – RESULTS FOR STEEL PROFILE COMPARISON

Not taking in account the transversal reinforcement aspects, it is stated that the shear connection degree does not have influence in the global analysis of two-span beams, except for small connection degrees, as this only influences the positive resistant moment which is not the most critical in situations where the spans have equal lengths (Illustration 5.3). When using different relations for the span length, the connection degree becomes an important subject as positive resistant moments start to be critical for the safety check.

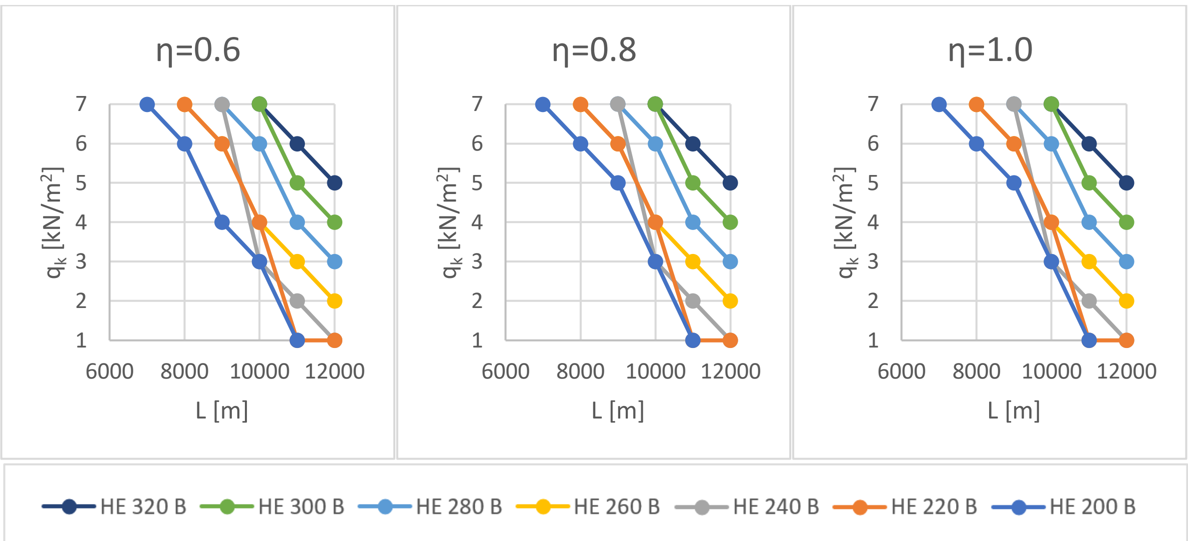

ILLUSTRATION 5.3 – RESULTS FOR SHEAR CONNECTION DEGREE COMPARISON

Still for the span relation analysis, results show that smaller steel profiles have better behavior for higher spans ratios, and it's explained by the higher shear stresses when using low span ratios. For bigger steel profiles the problem is related to the lateral buckling problem, and the higher span ratios are worst as they decrease de C4 coefficient in the elastic critical moment evaluation. So, the best ratio for the span lengths is situated between 80 and 85% (Illustration 5.4).

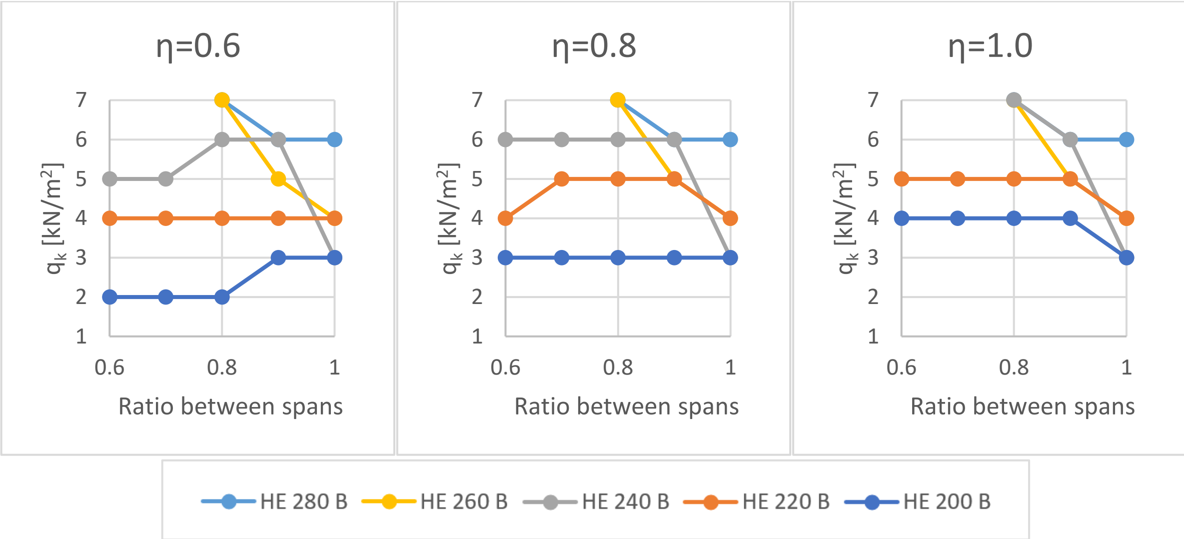

ILLUSTRATION 5.4 – RESULTS FOR SPAN RATIO COMPARISON

Regarding the materials, it is noticeable the indifference on the choice of concrete type as this only affect the positive resistant moment and, therefore, it's not relevant for the global analysis (Illustration 5.5). Besides this, the slab height variation was inconclusive because it has to many parameters depending on it. In fact, changing the slab height not only increases the load on the beam, also changes the lever arm for resistant moment evaluation and the rigidity of the slab for lateral-torsional buckling. The only advantage of higher slab heights is to reduce the stress on the compression strut for transverse reinforcement checks.

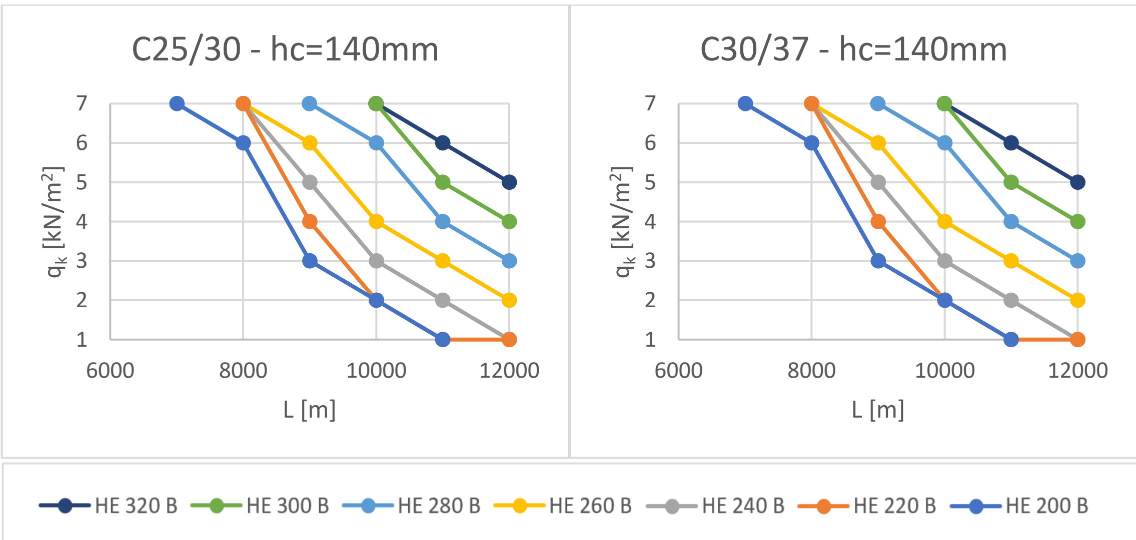

ILLUSTRATION 5.5 – RESULTS FOR CONCRETE TYPE COMPARISON

The most expected parameter to influence the resistance of composite beams is the type of steel selected (Illustration 5.6). It governs the cross-section classification, as a bigger steel yielding stress is worst for classification. Also dictates the reduction factor for lateral-torsional buckling consideration and, as the classification, a higher yielding stress implies a worst scenario.

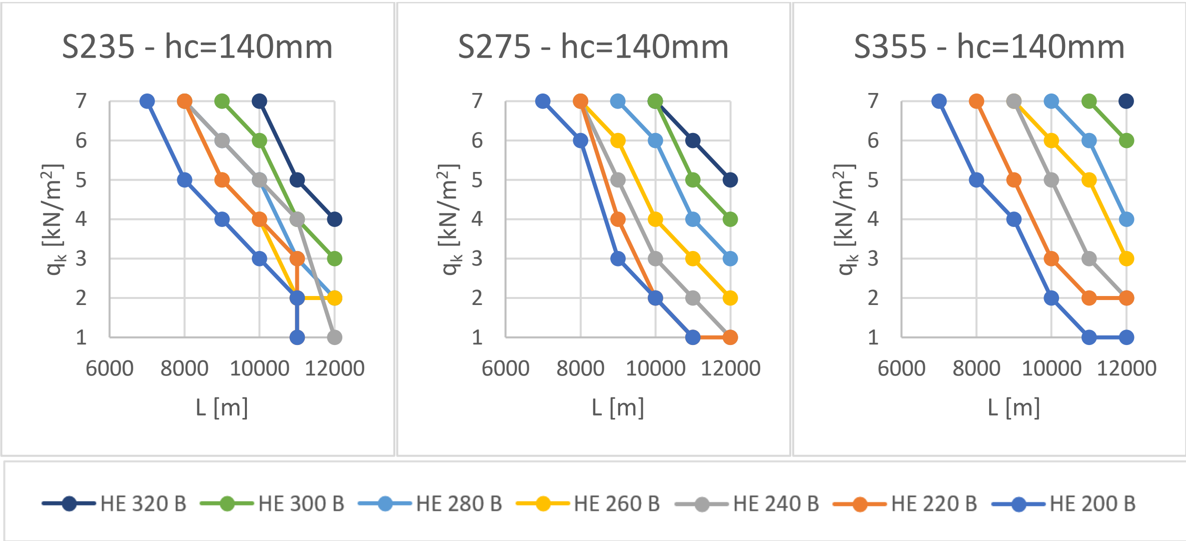

ILLUSTRATION 5.6 – RESULTS FOR STEEL TYPE COMPARISON

For bigger profiles, like the HE 320 B and HE 300 B, an increase in the steel yielding stress induce a higher number of situations where it verifies the safety. However, for the other profiles, this is not as clear and there are situations where the transition between S235 and S275 reduce the number of safe situations; whilst they increase again for the transition to S355. The reason behind this behavior is that lateral-torsional buckling prevents a redistribution to optimize the bending moment diagram, and thus being worst to verify safety. Investigating the analysis report, it's clear that also the interaction between bending moment and shear stress could cause problems and for higher yielding stresses this is not a problem. Nevertheless, the increase in bending resistance is undeniable (Table 5.1).

TABLE 5.1 – RESULTS WITH RESULTS FROM ANALYSIS REPORT

STEEL TYPE	$M_{PL,RD}$ AT SUPPORT	M_{RD} VARIATION	M_{ED} AT SUPPORT
S235	-485,81 kNm	0	-469,00 kNm
S275	-549,14 kNm	13%	-625,33 kNm
S355	-662,38 kNm	21%	-625,33 kNm

6. Conclusions and Future Work

Building Information Modeling

The biggest concern nowadays is the productivity stagnation in the construction industry, allied to the economy deceleration and lack of investment. This confirms the need to a new approach, and BIM has the potential to start the paradigm shift, by giving answers to the difficulties found by all the stakeholders of a project, namely the developer, designer and contractor. A project may be more than a group of drawings, as it transforms into a big data base that could be manipulated in order to assess the design performance since the start till the structure's end of life. Even though, there are limitations and difficulties associated to the shift of design workflow, legislative restrictions and technological equipment. Those changes also represent an important investment for the companies that can lead to a more prolonged implementation.

Parametric Analysis

Results show that smaller spans are more demanding for transverse reinforcement verifications. Also, bigger shear connection degrees have a similar effect to this matter. The size of selected steel profile is a crucial factor for the transverse reinforcement, as bigger profiles are more demanding.

Not considering the transverse reinforcement verifications, the shear connection degree is not relevant for two span beams. For continuous beams with different span lengths, this affirmation is not true as positive moments could lead the safety verifications, and the best span ratio is between 80 to 85%.

Regarding materials, the concrete as shown no influence in the verification. The slab height, on the other hand, has results that cannot be interpreted as they were influenced by the many aspects reliant on this parameter. Contrariwise, the steel type was very effective in terms of section resistance and is by far the best constraint to improve safety verifications.

In the future, the evaluation of different configurations of headed stud connectors should be considered, to check for the response in terms of transversal reinforcement. It's also important to evaluate the difference between two-span beams and continuous beams with more spans, and find the number of spans that have the best behavior. For the toolkit, should be implemented the Serviceability Limit States, steel profile sheeting for slabs and partially encased beams. Another challenge is to connect this toolkit to a BIM enabled programs, to complement the structural information with other relevant information.

References

Calado, L. & Santos, J., 2013. *Estruturas Mistas de Aço e Betão.* 2 ed. Lisboa: IST Press.

CEN, 2004. *EN 1994-1-1, Eurocode 4: Design of composite steel and concrete structures - Part 1-1: General rules and rules for building.* Brussels: European Committee for Standardization.

CEN, 2005. *EN 1993-1-1, Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings.* Brussels: European Committee for Standardization.

ISO, 2008. *ISO 13918, Welding - Studs and ceramic ferrules for arc stud welding.* 2 ed. Geneva: International Organization for Standardization.

Johnson, R. P., 1994. *Composite Structures of Steel and Concrete - Volume I: Beams, Slabs, Columns and Frames for Buildings.* 2 ed. Oxford: Blackwell Scientific Publications.

Nawari, N. O. & Kuenstle, M., 2015. *Building Information Modeling Framework for Structural Design.* Boca Raton, FL: CRC Press.