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Survey and solutions for potential cost reduction in the design and construction process of nearly zero energy multi-family houses

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Abstract. While the day in which nearly zero energy buildings is quickly approaching, their construction cost remains higher than minimum requirements' ones, in this framework operates CoNZEBs (Solution sets for the cost reduction of new Nearly Zero-Energy Buildings) Project, funded EU Horizon 2020. This paper explores a critical point identified by the project: potential cost reductions in the design and construction process. Starting from current costs and assessed the lack of available data, a survey is carried out focusing on two main stakeholders: i) design and planning process actors; ii) construction companies and contractors. About 100 answers are collected within the participant countries (Denmark, Germany, Italy, Slovenia), providing insights about issues and potential solutions for the process cost reductions. The results show differences among countries in terms of expectations for the potentials solutions, mainly related to the national market characteristics. The survey also shows the critical issue of the increase for construction costs respect to the originally planned ones. Another session presents the impact of exemplary solutions aimed at optimising the design and construction process costs; they are grouped in three categories: specific building envelope and energy system technologies, specific design solutions, innovative project management systems. Quantitative examples are provided for each category.

1. Introduction

Nearly zero energy private buildings will be mandatory in EU for new construction by 2021 and the date is anticipated to 2019 for public buildings [1]. Being current energy codes based on minimum requirements levels in Member States, it is expected an increase, significant in some cases, of the construction costs in the next years. This topic is crucial for weaker social classes, since this increase will also apply to the housing sector, and in particular in public and private social housing. The EU funded the CoNZEBs Project (Solution sets for the cost reduction of new Nearly Zero-Energy Buildings), in the framework of the Horizon 2020 Programme, with the objective of identifying methods, solutions, technologies able to reduce the construction costs of multi-family houses [2]. It has to be noted that residential buildings account for about the 75% of the total EU building stock [3], however the focus on multi-family houses is related to the fact that this typology is the most recurrent among low income people. What emerges from literature studies is that cost-optimal levels and packages of energy efficient measures strongly depend on national conditions. These differences are due to several variables such as: climatic conditions, energy, material and labour prices, available technologies and building types [4][5][6][7][8]. From the cited studies, it can be easily inferred that the building cost is assessed taking into expenditures for materials (including assembled components and systems, goods, etc.) and for labours. However, the overall costs include: design, permits, insurances, commissioning, preliminaries. The latter (also referred as indirect costs), in particular, are



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critical: they are defined as costs not explicitly related to the specific items of measured work but mainly related to the construction site "life cycle" (i.e. plant, accommodation, temporary services, rents, transport scaffolding, and insurances). Relevant data were collected in [9], according to this study preliminaries accounts for 10-15% of total construction project. This output stresses that relevant economic advantaged might be achieved by a more effective management of design and construction process, instead of scratching small savings from single energy related technologies. However, this issue is little explored, and there is a need of linking two main topics: the energy performance and the construction technologies in high performing buildings. The paper presents preliminary studies on how to approach and fill the gap.

2. Method

The review study carried out in the framework of CoNZEBs Project showed the lack of available data, needed to perform systematic and quantitative analyses to reduce costs in the design and construction process. Being a complex task and requiring big efforts to exhaustively cover this issue, the present study focuses on two relevant aspects, here preliminarily screened and that will need further in-depth analyses in the next future:

- I. The first phase regards the involvement of relevant stakeholders to better understand the main issues related to the design and construction process, and to identify areas for potential cost reductions. Actors involved in the design and construction process were asked to contribute via questionnaires and interviews on key topics.
- II. The second phase intends providing quantitative examples on methods, tools and technologies able to ensure cost savings across the whole construction process. This task is carried with the support of stakeholders, able to provide data from the market and from real experiences.

The outcome of the study is setting the ground for the implementation of new methodologies, in which the cost benefit analysis of energy analysis in buildings will take into account all the costs related to the construction process.

3. Involvement of stakeholders - Questionnaires and interviews

The questionnaire was implemented for a survey to be carried out in Italy, Denmark, Germany and Slovenia. Core issues were identified and addressed at EU level, however specific issues and topics were identified at national level; accordingly, the method to carry the survey was decided at national level, in most cases the questionnaires were distributed via email to relevant stakeholders and associations, in Denmark few relevant actors were identified and involved via direct interviews.

Two questionnaires were prepared targeting the actors involved in the two main phases and of the construction process:

- Designers and planners (individuals and studios)
- Construction companies, (social) housing associations and contractors.

Those companies are able to carry out the whole process, from cradle to grave, were asked to fill both questionnaires. It was also asked, when possible, to address the questions disaggregating the information for building minimum energy performance requirements and NZEB level. According to the study aims, the involved professionals were asked to provide information for the specific sector of multi-family houses. The questionnaire for designers/planners involved the following aspects:

- Actual design costs
- Method of determining the costs for design and planning
- Awareness and implementation of solutions to reduce design costs and to reduce costs during the whole construction process
- Experience and impact of the long-term maintenance costs.

The questionnaire related to the construction process included the following aspects:

- Magnitude and causes for cost variations in respect to the planned costs.
- Internal process implemented to reduce construction costs.
- Solutions to reduce overall construction costs (from cradle to grave).

For some specific questions, it was asked to rank the potential impact of a proposed solution to reach the indicated objective in a five-level classification from "No impact" to "Very high impact". The full results are presented in [9], here the main outcomes are presented and discussed.

The total of collected questionnaires and interviews was 95, ranging from individual designers to contractors with more than 2,000 employees. The majority of questionnaires were collected in Italy: 56; for Denmark, Germany and Slovenia were collected respectively 9, 15 and 12.

In this paper, the outcomes of four main questions are discussed:

- Assess the probability of the following solutions to reduce the design and planning costs from 5 (very high) to 1 (no impact at all) of NZEB buildings.
- Assess the probability of the planning and design solutions to reduce NZEB buildings costs in terms of overall construction costs from 5 (very high) to 1 (no impact at all)
- Rate from 5 (very high) to 1 (no impact at all) the following potential causes of relative cost change in current minimum energy performance buildings
- Assess the probability of the following solutions to reduce the construction costs from 5 (very high) to 1 (no impact at all)

The first two questions regard the design questionnaires, the other two are related to the construction process. The results are shown in figures 1 and 2.

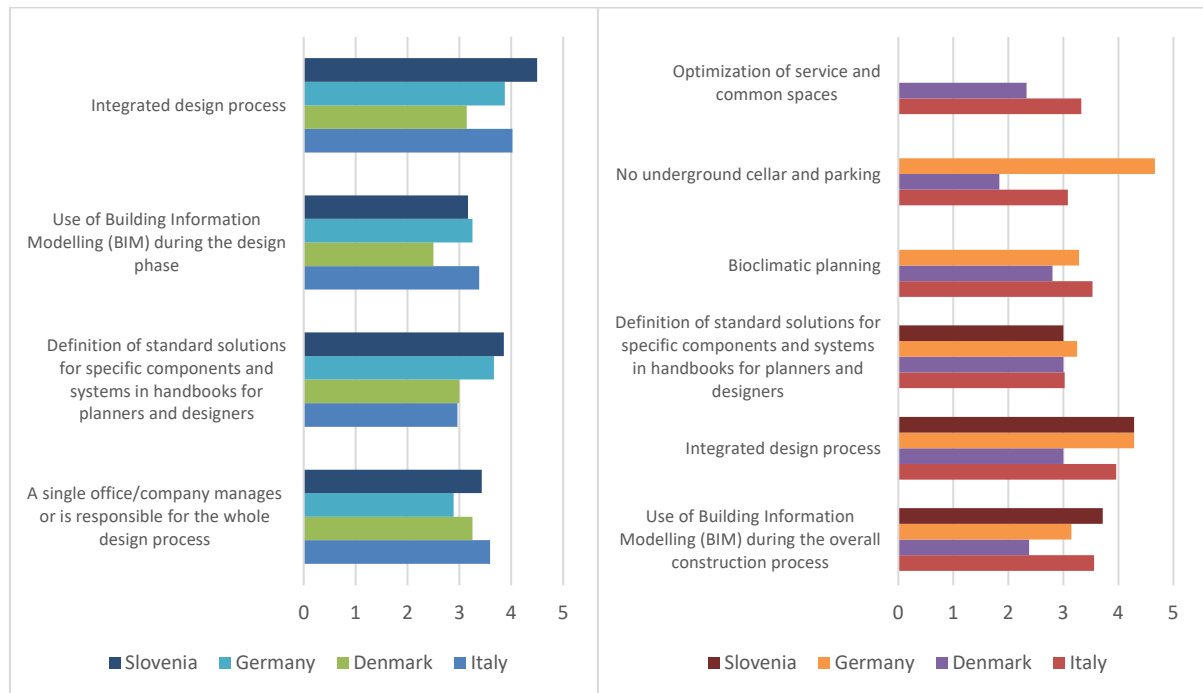


Figure 1. Design questionnaires: Average score of solutions to reduce design and planning costs (on the left); Average score solutions to reduce overall construction costs (on the right).

Concerning the capability of the proposed solutions to reduce planning costs, in all countries the most rated was the "Integrated design process" (Fig. 1). Nevertheless, scores of other solutions were not uniform among the four countries. In Italy the use of standard package and systems in the design phase is seen as a limitation to the creativity of the planners. On the contrary in Germany and Slovenia it was rated good. Comments of the interviewed also revealed that the use of BIM in Italy, Denmark and Slovenia is still poor: it is considered an innovative solution but the feasibility to apply it is still remote. Regarding the reduction overall construction costs by applying optimized design solution, in Denmark, Slovenia and Italy the "integrated design process" was rated again the best, while the lowest score was given to the absence of underground cellars and parking (Fig 1). On the contrary in Germany avoiding construction of underground cellars and parking got the highest score.

Disagreements were noticed among the Italian interviewed about the efficiency of bioclimatic planning. In Slovenia also, bioclimatic planning was rated 0, being considered ineffective and expensive. In Germany the solution “Bioclimatic Planning” was replaced by the “External Staircases”, which got an average score of 3.3.

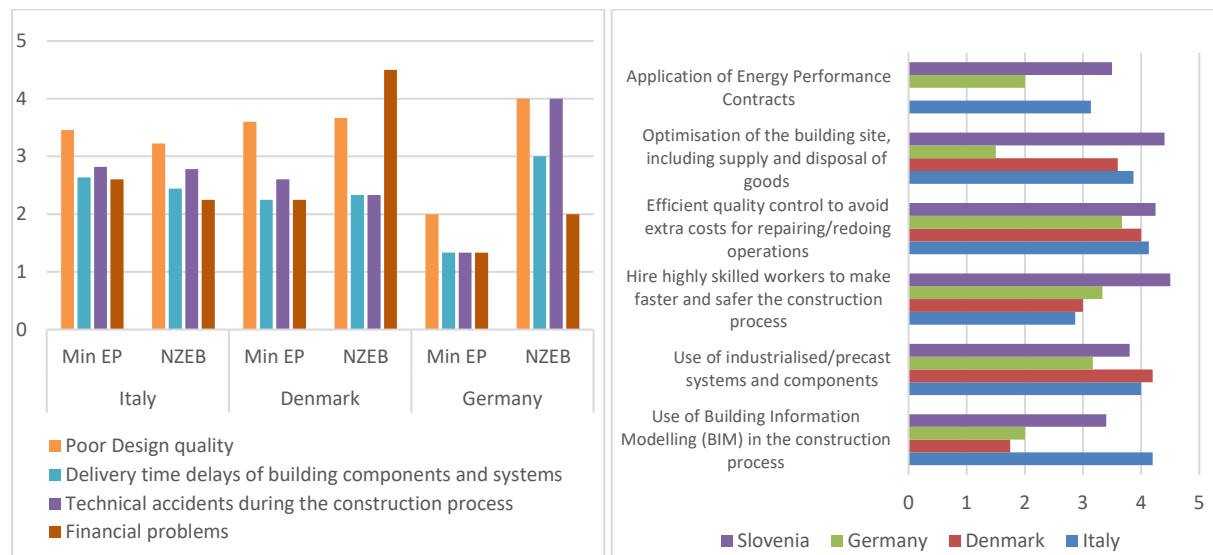


Figure 2. Construction questionnaires: Average values of Potential causes for increased construction costs in Minimum Energy Requirements Buildings and NZEB (on the left); Average values of probability of the proposed solutions to reduce construction costs (on the right).

The question about the potential cause for increased construction costs in current energy performance requirements buildings was answered only in Italy, Denmark and Germany; the most quoted answer is the same in the three countries: the “Poor design quality” (Fig. 2). It was also rated as the most influencing aspect for NZEBs in Italy and Germany. Conversely in Denmark, the most occurring cause of costs increase in NZEBs is “Financial problems”. When asked to evaluate the probability of a set of solutions to reduce construction costs, contributors on average quoted the most the development of “Efficient quality control in each phase of the process to avoid extra costs”, followed by “The use of industrialised/precast systems and components”. In Slovenia it’s also important to have skilled workers and to optimize the building site.

4. Exemplary solutions to reduce costs in the design and construction process

Several aspects related to cost reduction were investigated, the results are available in [9], here the attention is focused on the impact of alternative building technologies on the process costs. The activity was carried out with the involvement of manufacturers, asked to simulate construction time and costs of selected solutions to be compared with standard technologies in typical use cases.

4.1. Autoclaved aerated concrete (AAC) blocks

This technology was analysed for NZEB in Italy, where the most used technique for external facades consists of brickworks and ETICS. These blocks are based on natural elements and reach very high insulation and lightweight properties, thanks to a specific production process which creates micro air bubbling inside the material. The AAC blocks come with standard height and length, and different thickness so to achieve the needed thermal resistance. Being their thermal conductivity 0.12 W/mK and block thickness up to 50 cm, 0.15 W/m²K thermal transmittance is reached with a single layer, including internal and external finishing. According to the above, the AACs require a single working cycle, while the current technologies require one cycle of masonry work and one cycle for the insulation layer. The assessment was carried out for a typical Italian multifamily house with 1,436 m² of facade with thermal transmittance 0.22 W/m²K.

4.2. Monoblock windows

Mono-block windows (MBW) are components fully manufactured in the factory directly mounted in the facade hole and then fixed. The main advantage respect to conventional windows is the reduction of costs (material, labour and transport) for windows' sub-frames, which are installed during the masonry working cycle, hence before the windows' installation. Mono-block windows have the same thermal and solar performance of conventional windows of equivalent frame profiles and glazing unit. The advantage is less material and reduced labour. The assessment was carried out for the typical buildings, equipped with aluminium windows with thermal breaks and low-e coated double glazing unit. The thermal transmittance ($1.2 \text{ W/m}^2\text{K}$) complies with the national requirements.

4.3. PV solar roof

This is a brilliant case of BIPV (building integrated photovoltaics), in which the solar roof (PVR) completely replaces the traditional roof with the PV plant mounted on top. The PV modules entirely overlap the roof surface, providing a watertight cladding, while the underlying construction is the same as for the traditional roof. To optimise cost and performances, the PV-roof is typically made for the roof pitches oriented to the sun, while “dummy” and totally similarly looking roof plates are used on the opposite roof. The solar roof is made of thin film PV in frameless panels often with a black and homogeneous surface providing a simple and calm look. Special modules are supplied for part of the roof that cannot be uniformly covered (e.g. corners, skylight, etc.). The assessment of conventional and solar roofs is carried out for a typical Danish building with 240m^2 of roof PV.

4.4. Hygro-thermal ventilation

Hygro-sensible (HSV) ventilation is a controlled forced in which the flow of forced ventilation is regulated by materials that react to the relative indoor humidity: when the room is not occupied, the flow is kept at minimal level; when occupants are in, the flow increases to a level that ensure adequate indoor air quality. The air enters into the room through special rosettes with a hygroscopic tape, the fans exhaust the used air through slots in or under the door and continues the way to the sanitary facilities and the kitchen. Hygro-sensible ventilation systems are not equipped with heat recovery, as a consequence it will require additional energy for space heating in comparison with a typical NZEB ventilation system. The impact should be carefully addressed in terms of energy performance, here the assessment is carried out at economic and work time levels.

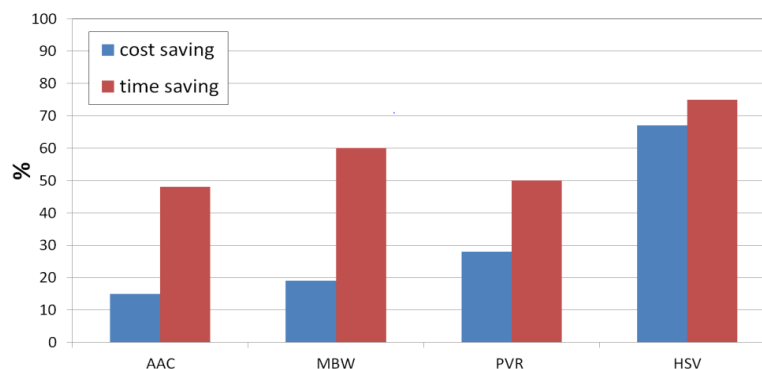


Figure 3. Cost and time savings of alternative technologies.

The results of the assessment are presented in figure 3, and clearly prove the strong impact of alternative technologies on the construction time, this result is critical since it affect the potential cost savings achievable reducing the construction phase and the related costs included in the preliminaries.

5. Conclusions

The study documented the potential for cost reduction in the design and construction process of nearly zero energy multi-family house, as perceived by the relevant factors involved in the process, thanks to a survey that covered close to 100 respondents. The questionnaires and interviews proved that slightly

different expectations are observed according to the country, but some core issues are relevant everywhere: the need of developing an integrated design process in the planning phase in order to avoid extra costs got the highest score in the four countries. A similar result emerged also in the construction questionnaires: when asked to assess the best solution for reducing construction costs, contributors in the four countries quoted the most the development of "Efficient quality control in each phase of the process". Furthermore, the most occurring potential cause of construction cost increase in minimum EP buildings and NZEB is "Poor Design Quality". A critical issue resulted to be the optimisation of construction site lifetime, to be carefully addressed since the preliminary planning. This has a strong impact on ensuring the respect of the works schedule, minimise extra-costs, reduce preliminaries and site related cost. The assessment carried out in the study proved that technologies able to provide construction time savings beyond cost saving exists. These outcomes ask for new methodological approaches in which the cost benefit analysis takes into account the whole construction process (from preliminary planning to commissioning), instead of actual methods, taking into account only the cost of technologies and the associated labour.

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