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Life cycle cost modelling using 6D BIM in construction: A comparative study

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Abstract. Life Cycle Costing (LCC) and Building Information Modelling (BIM) are among the important current trends in the construction industry. LCC contributes to the objective management and measurement of costs during the entire lifetime of a building and BIM represents one of the digitalization efforts related to the Construction 4.0 initiative. Because life cycle cost modelling using 6D BIM has the potential to bring significant positive effects such as cost savings and reduced environmental burden, this paper aims to study the development of this concept in the Czech Republic and Austria. The legislative environment, the actual usage of LCC and BIM in practice, as well as problems faced by the Czech and Austrian construction industries, are discussed in this comparative study. The results show that the practical level of use is still relatively low in both countries, yet specific differences were identified, for example those related to the definition of legislative requirements and the availability of standards and specifications.

1 Introduction

The construction industry is often criticized for its poor performance [1] manifested in various areas such as time, cost, quality, and productivity. Many construction projects fail to meet their targets, resulting in time and cost overruns or quality issues that can lead to disputes [2–4]. In this regard, great expectations are associated with advancing digitization in the sector, which is referred to as Construction 4.0. It is believed that the Construction 4.0 initiative will positively contribute to the overall performance in several ways, e.g. in terms of automation leading to cost and time savings, reducing error margins, improving site safety, and reducing risks in general. In this context, the issue of data availability and its management will be central.

Building Information Modelling (BIM) represents one of the main recent digitalization streams in the construction industry. Azhar [5] defines BIM as a "virtual process that encompasses all aspects, disciplines, and systems of a facility within a single, virtual model, allowing all design team members (owners, architects, engineers, contractors, subcontractors, and suppliers) to collaborate more accurately and efficiently than using traditional

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processes". BIM does not comprise merely the creation of three-dimensional intelligent models as it can also be used in sophisticated ways for the purpose of cost estimating, construction sequencing, conflict, interference and collision detection, forensic analysis, and facility management within the building's entire life cycle ranging from the early conceptual stage through the design stage, construction stage, operation and maintenance (use) stage to demolition [5,6]. In this regard, the literature recognizes several BIM dimensions, namely 4D (scheduling) and 5D (costing). Although the general consensus is achieved for the 4D and 5D dimensions, there exists no agreement on 6D and onwards [7].

In this paper, we focus on the 6D dimension of BIM. According to Nicał and Wodyński [8], 6D BIM is primarily oriented towards improving facility management practices as it focuses on the post-construction operation and maintenance phase. It is believed that 6D BIM adoption and implementation in organizations will positively contribute to more efficient design solutions and an economical way of operating various types of facilities. Benefits do not relate just to the financial perspective but also to the environment, for example in terms of reduced energy consumption and the use of environmentally friendly materials. That is why 6D BIM issues are highly topical and essential for the construction industry.

Despite great efforts to promote, implement and use BIM in the construction practice, actual progress is largely limited. Therefore, it is desirable to address the extent to which these efforts have actually been successful. Substantial differences exist between European countries. For example, Charef et al. [9] reported that BIM implementation at the national level does not yet exist in some EU countries, while in other countries BIM technology has been used for more than a decade. Accordingly, our motivation is to contribute to a deeper understanding of these differences. In particular, the main aim of this paper is to describe, analyse, compare and discuss the current state of 6D BIM application in the Czech and Austrian construction industries.

2 State-of-the-art in the Czech Republic

2.1 General view on BIM adoption and use

The legislative path to the implementation of BIM in the Czech Republic started on 2 November 2016, when the government recognized the importance of BIM for construction practice (Government Resolution No. 958 on the importance of Building Information Modelling (BIM) for construction practice in the Czech Republic and the proposal for a further procedure for its implementation [10]). Later, on 25 September 2017, the Government approved the Concept of Implementation of the BIM Method in the Czech Republic (by Decree No. 682, [11], hereinafter referred to as the "Concept"). The Ministry of Industry and Trade serves as the guarantor of the process of BIM implementation in the Czech Republic, while it is executed by the BIM Concept Department of the Czech Standardization Agency. For this purpose, 7 working groups have been established, namely:

- WG01 – Pilot projects;
- WG02 – Public procurement, project management and contracts;
- WG03 – Standards of data and information requirements;
- WG04 – Data and information for cost management;
- WG05 – Education, marketing;
- WG06 – Terminology and standards;
- WG07 – Facility management (2019).

Regarding the topic of this comparative analysis, WG02 should provide the most relevant standards and methodologies, in particular, to compile the documentation for a building evaluation. Furthermore, the Agency recognized the importance of the operation and maintenance phase and has, therefore, recently established WG07, which should prepare and test the rules for passporting within the above-mentioned stage in connection with the already developed Data Standard for Buildings. In Table 1, the development of BIM in the Czech Republic is shown in three selected years (2013, 2018 and 2022).

The Concept assumes that from 2024, public contractors will have to start using BIM methods for all above- threshold construction contracts (obligatory usage). Although this obligation relates only to public contractors, it is expected that it will significantly affect the entire construction sector. Additionally, a special “BMI Act” is being drafted now. From a legislative point of view, this Act will impose an obligation to process BIM for above-threshold public construction contracts.

Table 1. Development of BIM in the Czech Republic (based on [12])

2013	2018	2022
Problems	**Solutions/ progress**	**Actual situation/ efforts**
Lack of BIM definition in legislation and standards	New documents: BIM Guide, BIM Guide for investors, creation of standards	Updated time schedule – BIM since 2024 for above-threshold public contracts (> EUR 6,000,000)
Low interest on the part of the government and investors	Government strategy for the implementation of BIM in large projects since 2022; Construction 4.0 initiative	Focus on the information model of a building, Common Data Environment and contractual arrangements for the use of BIM and BIM protocol
Lack of experienced experts	Several pilot projects, large contractors, and investors are working with BIM; positive development also in the area of education (universities and secondary schools)	Increase the number of pilot projects (recommendation for the State Fund for Transport Infrastructure: the use of BIM in 20% (2021) and 60% (2022) of the projects
Missing motivation	The market now creates motivation by itself to be prepared in connection with the governmental strategy	Transformation of organizations into “digital organizations”

2.2 LCC management and BIM in the Czech Republic

The problems related to the application of the life cycle cost principle in the context of BIM can be split into two dimensions. The first dimension is the issue of building construction cost estimation. Traditionally, building cost estimation is carried out by a bill of costs (itemized budget) with a statement of measures (bill of quantities). Relevant information for cost estimation is taken from Czech price databases (URS, RTS etc.) [13-15], where it is possible to find indicative unit prices, consumption norms and other necessary information.

Construction cost estimation using the BIM model represents assigning costs to quantities in the model (when speaking about DBB, i.e. measured contract) [14,16]. In the Czech Republic, companies providing cost estimation software develop support for cost estimation in BIM. For example, the RTS Plugin [17], BIM PLATFORMA [14, 18, 19], BIM CALIDA [15], FORGEE solutions can be mentioned. The cost estimation process in BIM is essentially very similar to the traditional one, but the difference lies in the extraction of measurements, which makes up about 75% of the construction economist’s work. For instance, it is not necessary to count volumes of concrete, areas of plaster or numbers of prefabricated columns manually. Hence, it can be said that BIM reduces the human resources needed in cost estimation and also reduces the occurrence of errors.

However, due to the specific characteristics of cost estimation in the Czech Republic, certain problems arise and need to be resolved in order to contribute to the full automation of the process. The main issues are as follows: (1) methods of measurement; (2) reporting and classification of elements; (3) occurrence of unmodelled structures like scaffolding and formwork; and (4) additional information that is not modelled, e.g. excavation soil class. An example is shown in Fig. 1.

1	781111011	Sweeping (dusting) of the wall during preparation of the substrate	m^2	CS ÚRS 2023 01
2	781121011	Penetration coating (primer) for wall	m^2	CS ÚRS 2023 01
3	781131112	Insulation under the tiling by coating or paint in two layers	m^2	CS ÚRS 2023 01
4	781131232	Insulation under tiling with sealing strips for contact or dilatation joints	m	CS ÚRS 2023 01
5	781474117	Installation of smooth interior ceramic tiles from over 35 to 45 pcs/m^2 glued with flexible adhesive	m^2	CS ÚRS 2023 01
6	*59761255*	*smooth ceramic tiles from over 35 to 45 pcs/m^2*	*m^2*	*CS ÚRS 2023 01*
7	781495192	Surcharge for interior tiles for parquet tile pattern	m^2	CS ÚRS 2023 01
8	781474152	Installation of large smooth interior ceramic tiles from over 0.5 to 2 pcs/m^2 glued with flexible adhesive	m^2	CS ÚRS 2023 01
9	*59761634*	*large smooth ceramic tiles from over 0.5 to 45 pcs/m^2*	*m2*	*CS ÚRS 2023 01*
10	781474154	Installation of large smooth interior ceramic tiles from over 4 to 6 pcs/m^2 glued with flexible adhesive	m^2	CS ÚRS 2023 01
11	*59761001*	*large smooth ceramic tiles from over 4 to 6 pcs/m^2*	*m^2*	*CS ÚRS 2023 01*
12	781491012	Installation of mirrors with an area of over 1 m^2 glued with silicone sealant on the base plaster	m^2	CS ÚRS 2023 01
13	*63465122*	*clear unmounted mirror, 3 mm thick, max. size of 3210 x 2250 mm*	*m^2*	*CS ÚRS 2023 01*
14	781494111	Plastic corner profiles glued with flexible adhesive	m	CS ÚRS 2023 01
15	781494511	Plastic end profiles glued with flexible adhesive	m	CS ÚRS 2023 01
16	781495115	Jointing of interior tiles with silicone	m	CS ÚRS 2023 01
17	998781103	Transport of materials – ceramic tiling in buildings, from 12 to 24 m, calculated by weight	t	CS ÚRS 2023 01
18	998781192	Surcharge for transport of materials by weight, 781 for longer transport up to 100 m	t	CS ÚRS 2023 01

Fig. 1. Cost estimation export using BIM, source: authors (BUT BRNO)

Fig. 1 shows an example of a bill of costs exported from a Czech software for interior wall tiling. Individual items are coloured based on compatibility with BIM cost estimation. Green items are structures that directly correspond to (are reported in) the model. Orange colour represents items that are not reported, but the information is available in the model (e.g. the information on the composition of a building structure or information in a technical report). For example, in the example shown, this is a primer or a waterproofing sealer under the tiles. Blue colour identifies items of information that cannot be found in the model, but must be included in the bill of costs (e.g. sealing insulation strips). Grey colour indicates the transport of bulk materials. The estimation of bulk materials transport depends on the weight of individual material items. This weight cannot be reported from the BIM model, however, cost estimation software makes this calculation possible. Items that are directly reported from BIM make up only about half of all items. It is not possible to rely exclusively on BIM for correct cost estimation in the investment phase of LCC at this moment.

Construction cost estimation using BIM is still in its infancy in the Czech Republic. It is necessary to solve the issue of classification and the methodology for correct measurements in the design phase. The classification itself is currently handled by the Czech Standardization Agency. Significantly better cooperation and communication between the designer/architect, the construction economist and facility management are needed. In particular, designers need to understand which information, classification and details are important for cost estimation.

In the Czech Republic, life cycle costs (LCC) are used as an evaluation criterion for the economic viability of a tender for a public works contract. According to Section 117 of the Public Procurement Act [20], it must include the tender price and may include: (a) costs incurred by the contracting authority or other users during the life cycle of the subject of the public contract; or (b) costs caused by environmental impacts associated with the subject of the procurement at any time during its life cycle. An important condition for the use of this evaluation criterion for public works contracts is the award of a Design & Build (D&B) contract. This means that the project must be specified through the requirements for the purpose and function of the facility so that the contractor has the opportunity to select the workflow technologies that will deliver the desired operational outputs (e.g. operational cost savings).

Despite the fact that the general formula for calculating LCC is stated in the Act [20], there is no practical guidance or methodology on how to calculate these costs in detail. Furthermore, there is no extensive database on the maintenance and repair costs of real existing buildings and on the lifespan of individual structures within the operational phase of the life cycle.

Taking the above into account (problems with construction cost estimation using BIM, missing detailed methodology and database), it is clear that the practical use of the combination of LCC and BIM in practice is rather the exception in the Czech Republic. Despite the slow pace of progress in this area, there are some exemplary projects that have been implemented using BIM, LCC and D&B. These examples include the construction of the Supreme Audit Office headquarters, considering the costs of operation and renewal of the technical equipment of the building according to the established methodology over a period of 30 years and the qualifications and experience of the members of the implementation team [21]. It should be noted that a special LCC calculation methodology has been developed for this particular case.

3 State-of-the-art in Austria

3.1 Life Cycle Costing

Due to the increasingly holistic approach in the construction industry, which takes into account the economic, ecological and social aspects over the entire life cycle of a building, buildings are no longer assessed solely on the basis of production costs. The evaluation of tenders for public clients on the basis of life cycle costs is provided for as an option in the Austrian Federal Procurement Act, but without mandatory application [22].

According to the Austrian Engineering and Architectural Journal of the OIAV [23], life cycle costs are the measure of the economic sustainability of buildings [24]. According to this, a decisive factor is the building technology with an economic life span significantly below the entire life span of a building. This means that a large part of the costs in the life cycle must be spent on the repair of the building services engineering. The working group

"Life cycle costing in the awarding of contracts" of the IG Lebenszyklus Bau has prepared a guideline in this context [25].

A study [26] by FH JOANNEUM, in which an analysis of facade systems was carried out, makes it clear that the sole consideration of manufacturing costs cannot be a sufficient basis for the selection of a facade construction. Only by including the follow-up costs through the use phase and after-use phase can a reliable decision-making aid be obtained, since only in this way the total life cycle costs are taken into account.

With a life cycle costing (LCC), various decisions can already be made in the planning phase with regard to the effects over the entire period of the life cycle of a building, in order to ultimately optimize investments.

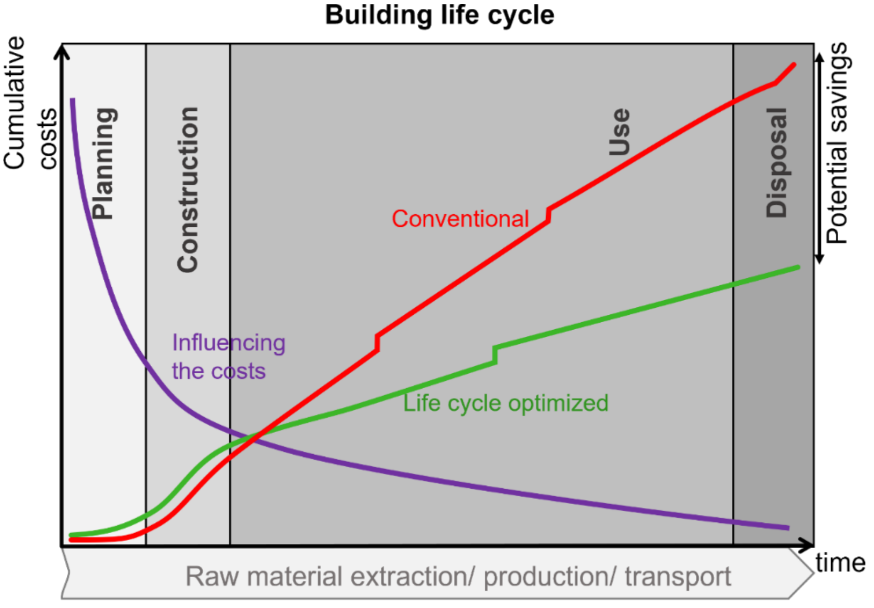

Fig. 2. Life Cycle, source: FH JOANNEUM

The calculation of life cycle (Fig. 2) costs is based on procedures of the current standards according to ISO 15686-5 [27] and ÖNORM B 1801-1 [28], B 1801-2 [29] and B 1801-4 [30], as well as on guidelines such as GEFMA 220 [31] and VDI 2067-1 [32]. On the one hand, general building data, more detailed component data and, on the other hand, corresponding key figures are used as a basis.

The source Life Cycle Phases, ISO 15686-5:2017-07 [33] shows the relationship between "life cycle costs" and "whole life costs" in order to illustrate the entire life cycle of a building from conception, planning, construction, and use (including maintenance and servicing) to demolition or disposal.

For the assumption of the expected service life of the respective components or elements, empirical values from guidelines, e.g. service life tables of the experts [34] or the guidelines for sustainable construction [35] and ISO 15686- 8 [36] are used.

The other calculation parameters for obtaining the life cycle costs according to modern investment calculation, such as the period under consideration, the calculation interest rate, and price increases, are selected according to the recommendations of guidelines or certification systems.

3.2 BIM adaption & use

The currently valid government program from 2020 to 2024 in Austria stipulates that BIM should be increasingly taken into account in public procurement [37]. Public contracting authorities must comply with the Federal Procurement Act 2018 (BVergG 2018) when awarding public procurements. In this Act, BIM and its application are not explained in any of its paragraphs [38]. In Austria, however, there have been guidelines for the application of BIM at the standard level since 2012. On 1 May 2012, the ÖNORM A 6240-4 for digital documentation was published in Austria. Based on this, this standard was replaced three years later on 1 July 2015 by the currently valid series of ÖNORM A 6241.

The structure of this series of standards is based on the milestones of the BIM development stages. For the “Level 2” development stage, the implementation of data exchange and data management as well as terms, structures and databases are specified [39]. In addition, the second part deals with “Level 3 iBIM”. The standard extends the scope of the previous guidelines from 3D to the sixth dimension. The structures create a normative prerequisite for a uniform, structured and multi-dimensional data model basis for collaboration over the entire life cycle. Planning, execution, management, demolition and disposal are to be taken into account. The exchange of graphical data and metadata on the basis of IFC (Industrial Foundation Classes) and bSDD (building-SmartDataDictonary) is to be made possible [40].

For a uniform and product-neutral exchange of data, the ASI (Austrian Standards Institute) Characteristics Server is used in Austria as a free web service [41]. No data is stored on this server, which is freely accessible via the Internet; only the data description is defined [42].

In Austria, extensive and detailed normative prerequisites have already been created, making Austria a world leader in this respect [43]. The survey in the Fig. 3 below shows the spread of the use of BIM in Austria [44]. The survey was conducted with the organizations Fachverband Ingenieurbüros (ING), Ziviltechnikerkammer (ZT) and Bundesinnung Bau (BAU). Depending on the organization surveyed, at least one-third to almost one-half state that BIM is already being used in their organization. In contrast, 8 to 18% state that BIM will not be applied in their organization. All the other respondents will implement BIM in their organization over the next one to five years.

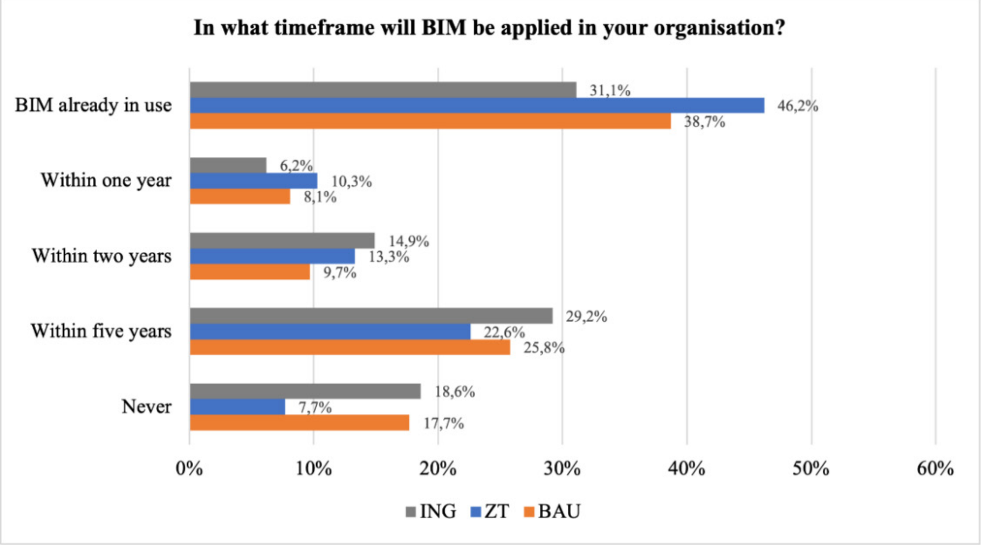

Fig. 3. Adoption of BIM in own organization, BIM-Handbuch 2022 [44].

The survey does not reveal the extent to which the application of BIM goes beyond mere three-dimensional building planning, and to which the fourth, fifth or even sixth dimension is also used.

Likewise, there is no quantifiable information on whether and to what extent the potential of digital building twins in the context of Facility Information Modelling (FIM) is used in the operation of buildings in Austria.

3.3 LCC & BIM in Austria

The EU taxonomy [45] and the Sustainable Finance Disclosure Regulation (SFDR) [46] are also intended to strengthen the implementation of climate protection targets in the real estate sector. In Austria, there are corresponding efforts at the political and legislative levels, particularly in the area of financing [47]. The calculation of the life cycle costs of a building could play a central role. This is also because the certification systems for sustainable real estate commonly used in Austria [48] take life cycle costs into account as a decisive evaluation criterion for the economic quality of the building.

While theoretical models already explain how life cycle costs can be calculated with the BIM method [49], [50], the practical application in the Austrian construction industry does not seem to play a role yet. Current ongoing research projects in Austria prove this assumption [51].

The software landscape and cost data especially in the area of operation and maintenance costs for real estate are currently heterogeneous, partly inconsistent or non-existent. This is evidenced by a Master's thesis at FH JOANNEUM from 2019, in which the calculation options for operating costs of a building with the BIM method were investigated and implemented on a trial basis [52].

4 Discussion and conclusion

The comparison made in the area of life cycle costing using 6D BIM in construction showed specific differences and similarities between the Czech Republic and Austria. First, we should highlight the differences in legislative concepts. In the Czech Republic, the Public Procurement Act imposes the obligation to use BIM in above-threshold public contracts starting from 2024 (this date has been repeatedly postponed). The Act also permits the use of the LCC as a criterion to select the best bid in a tender. In contrast, so far (and currently) no legal requirements for the use of BIM exist in Austria, even though this will probably change with the new EU taxonomy concerning the financing of constructions. The use of LCC, for example, as an award criterion for the procurement of public construction contracts is enshrined in Austrian law.

Sufficient standards and specifications for the calculation of LCC are available in Austria. In the Czech Republic, only generally formulated approaches to LCC calculation have been prepared, and the practical use of LCC therefore requires the development of a specifically tailored methodology. Regarding LCC calculation, the comparison of the state-of-the-art in the Czech Republic and Austria revealed that both countries miss relevant data and characteristic values for the determination of operating, utilisation and maintenance costs of buildings.

Specific limitations also relate to BIM-based cost estimation. In the Austrian construction practice, BIM is mainly used for three-dimensional planning; the fourth, fifth and sixth dimensions of the virtual building model are hardly used at all. Furthermore, there is very little practical experience in the Austrian construction industry with cost determination using virtual building models. In the Czech Republic, the specific cost estimation approach does not allow to export all dimensions of the construction work from the BIM model. Thus, the problem of determining costs with BIM support arises even when determining the cost of the actual construction. That is why this particular issue, together with efforts to make progress in determining costs in the consequent phases of the construction life cycle, represents one of the central areas of development for the Czech Standardization Agency.

The comparative analysis revealed only slow and little progress in the implementation of BIM and LCC in both the Czech Republic and Austria. For both countries, pilot projects are available or in progress. This represents a very significant step towards the more widespread use of BIM and LCC in future practice. In this context, it is essential that the knowledge and experience gained are shared within the professional community. Such sharing of knowledge involves not only the positives, but also the potential negatives. Only in that case can we expect that future projects will implement LCC and BIM approaches with less difficulty and will not repeat previous mistakes.

Finally, there is a very heterogeneous software landscape for BIM and the calculation of LCC using the virtual building model in Austria, so not all data can be exchanged easily via IFC. The software for creating and managing BIM in the Czech Republic is also based on the IFC standard. However, the current individual software solutions do not provide reliable and flawless connections in terms of cost calculation and LCC implementation.

This study qualitatively analysed the use of life cycle costing with 6D BIM by comparing the progress made, current problems and challenges in the Czech Republic and Austria. In terms of theory, this study expands the knowledge on the prevalence of the usage of modern technologies and approaches in the area of sustainable and digital cost estimation in two neighbouring Central European EU member states. Practically, the research demonstrates relatively slow progress in the context of the actual usage of these sustainable and digital methods and tools for cost estimation despite the considerable pressure for a more responsible approach in this area from the professionals, as well as political representatives on both national and EU levels.

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