Industry 4.0 - present and future trends in infrastructure and construction public-private partnerships in Europe: comparative perspective

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Abstract

There is a growing preoccupation concerning infrastructure and construction public-private partnership projects, in connection to Industry 4.0. This article analyses attitudes towards infrastructure and construction public-private partnerships in the context of Industry 4.0 in European countries from a comparative perspective. The study uses the time series analysis and a survey. The data series provided by the European PPP Expertise Centre (EPEC) have a yearly frequency, cover the time interval 2012-2020 and were provided by the EPEC website. The second research is based on the results of a survey conducted among public and private authorities involved in PPP projects in 6 European states in order to draw a comparative perspective. The survey focused on digital technologies in infrastructure and construction PPP projects, the respondents being asked to determine the opportunity of Industry 4.0 in PPP projects. The study carries on a European cross-country analysis on four major themes: (1) BIM-enabled PPP projects (BP), (2) Automation and Robotics in PPP projects (ARP), (3) Artificial Intelligence in PPP projects (AIP) and (4) Drone photogrammetry and laser scanning in PPP projects (DP). The results indicate that there are significant differences in respondents' views regarding the adoption of Industry 4.0 in PPP projects, still there is consensus that new, innovative researches are required in order to help states and companies increase their knowledge concerning PPP projects in relation to Industry 4.0 and their adoption options. The research highlights that both the state and the private companies must adapt and therefore invest in technology so as to optimize the adoption of Industry 4.0 in PPP projects, in order to increase the success of PPP projects.

Keywords

Public-private partnership; Industry 4.0; infrastructure; construction; Building Information Modelling; Automation and Robotics; Artificial Intelligence; Drone photogrammetry and laser scanning.

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Introduction

Public-private partnership projects are the backbone of economic development. By consequence, there is a need to encourage the investments in the PPP projects with the help of Industry 4.0. This article will explore particularly this gap in the literature.

In all sources related to PPP projects from the beginning of their implementation to the present, one of their main advantages is precisely the support of innovations that reduce operating and investment costs and the time required for the PPPs (Liu et al., 2023). The private partner is motivated by these innovations primarily for its own reasons - to make the greatest possible savings by constantly improving his processes, meanwhile the state administration is mostly rigid and bound by old regulations (Spahiu, 2020; Schin et al.,

2023). Still, "policymakers should promote public-private partnerships to boost the innovation, while easing the business environment." (Chen et al., 2021)

It can be said that nowadays the innovations brought about by the current age of digitization are the most discussed topic not only for PPPs but for all industries. The terms "Industry 4.0" or "Fourth Industrial Revolution" indicate this trend. The basic concept considers the progress of digitization and the development of PPPs in such a way that automated systems will gradually replace the majority of unskilled work and create new jobs with the need for higher qualifications. These changes will be introduced through emerging technologies such as artificial intelligence, cloud solutions, 3D printing, Internet of Things, self-diagnosis and other "smart" elements. It is assumed that all these changes will lead to savings in time, money and also correspond to the general trend of increasing the qualifications of workers, thereby increasing their purchasing power and ultimately the level of general well-being. (Akomea-Frimpong et al., 2022) It is therefore mainly up to the public sector and also private investors to require and drive innovation in their PPPs (Brogaard, 2021). Overall, there is a gap concerning the integration of Industry 4.0 innovation into PPP projects (Ma et al., 2019)

The current study contributes to literature and practice: first, the article analyzes the necessity of modernization of construction and infrastructure PPP projects from the perspective of Industry 4.0, which emerges as a new path in this area of study. Second, this article analyses attitudes towards infrastructure and construction PPPs in the context of Industry 4.0 in European countries from a comparative perspective. In addition, the methods used in this research are based on the time series data collected in the time interval 2012-2022 and a survey, both of them standing as a rigorous theoretical groundwork in the literature. The fourth contribution of the article is that it examines the attitudes of respondents from 6 states from Europe concerning Industry 4.0 and construction and infrastructure PPP projects.

In the first part of the article (Introduction), there will be provided a brief introduction on the subject, focusing on the relation between PPP projects and innovations. The second part will be a literature review made up of a selection of modern technologies and methods, focused mainly on their use within PPP projects having as key aim to catalyze their economic benefits and not only. The next section deals with Methodology. Section 4 highlights the Results and Discussion while section 5 presents the Interpretations. In the last section, the final conclusions are being presented.

Literature review

Before discussing the new trends in PPPs, several aspects should be pointed out. First, it is clear that there is practically no official definition of public-private partnerships (Khanom, 2010). Still, since the focus of the article will be on PPPs in Europe, the definition used will be that of Regulation (EU) 1303/2013 of The European Parliament and of the Council, according to which, a public-private partnership is "a form of cooperation between public bodies and the private sector, aimed at improving the delivery of investments in infrastructure projects or other types of operations, delivering public services through risk sharing, the pooling of private sector expertise or additional sources of capital." (EU, 2013, p. 320). Also, EPEC defines PPP as "an arrangement between a public authority and a private partner designed to deliver a public infrastructure project and service under a long-term contract", which, "when properly prepared, PPP projects can provide significant benefits to the public sector as well as to the project users." (EPEC, 2023) Second, every country incorporates the method of setting out contracts into its legislation in its own way (Cui, et al., 2018), even if, after years of experience there has been reached a general consensus as to which the basic characteristics of PPP projects are (Spahiu, 2020). In spite of this, their importance in regional and local development in most European countries is well known. The eleven-year view of the European PPP market by value and number of projects (2012-2022), can be seen in Figure 1.

In 2022, the aggregate value of PPP transactions that reached financial close in the European market totalled €9.8 billion, a 23% decrease from 2012 (€12 billion). Also, the number of PPP transactions reaching financial close decreased to 45, compared to 62 in 2012.

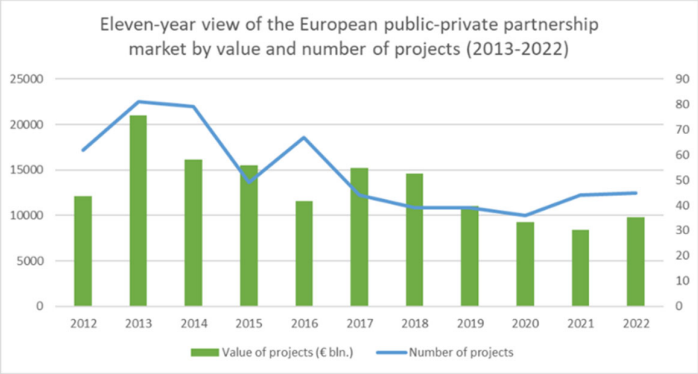

Figure no. 1. Romanian retailing Eleven-year view of the European public-private partnership market by value and number of projects (2013-2022)

Source: EPEC, (2023b) & EPEC (2023a). Evolution of the PPP market by year / all sectors Available at: https://data.eib.org/epec/sector/all, accessed on 13.11.2023

These statistics prove that, PPP projects are a new and still somewhat experimental way of providing and organizing public goods and services (Gromova et al., 2022). In order to understand how PPP projects can specifically catalyze digitization innovations, further on research will be drawn of several examples by which Industry 4.0 is preferred for infrastructure and construction PPPs and which, for example, in the case of BIM technologies, should be, in many respects, already a mandatory part of most PPP projects.

BIM. BIM technology is the absolute basis of all digitization efforts in the infrastructure industry and also probably the most talked about new technology in the industry in the last decade. There are many researchers who consider that "the integration of Building Information Modelling (BIM) and public-private partnership (PPP) approaches could reshape and transform conventional construction practices" (Xu et al., 2022) In this vein, studies focus on the development of "a building information modeling–based performance management system" (Yuan et al., 2020) for PPPs, BIM being often seen as a means leading to the improvement of "the collaboration and integration in the PPP projects" (Habib et al., 2020), while also increasing their sustainability.

Automation and Robotics. Automation and Robotics are practically synonymous with Industry 4.0. Maybe the most prominent in this regard is 3D printing technology, which makes it possible for machines to create entirely finished structures of simple constructions from concrete in a period that is many times shorter than when using conventional technologies. As an example of an advanced robot already used in real construction conditions, can be mentioned the Hilti Jaibot robot used in construction. The Jaibot completes its tasks based on BIM data (Xu et al., 2022). The robot is used to drill holes for anchoring systems of technical installations (electricity, water, air-conditioning and other distribution systems that run along the walls or ceiling). This is physically a very difficult work for a team of workers, and there are thousands of such openings on the construction site of large projects (Brosque et al., 2021).

Artificial intelligence. What robotics is to the physical construction of buildings, artificial intelligence systems can be to design, planning and other activities that are also an integral part of the construction/infrastructure industry. In the infrastructure construction, "the combination of digital technology and the PPP financing model can provide a more reasonable financing plan" (Wang and Cui, 2022). In the construction industry, artificial intelligence has many potential uses, although, like robotics, they are still mostly only at the prototype stage. In addition to self-driving trucks and autonomous construction machines, AI systems can be used, for example for: Design; Governance support (Bhatia, 2020); Increased security (Kruhlov et al., 2019); Better financial management of Public Private Partnership projects (Sharafi et al., 2016) since the investment and construction period with the help of AI techniques "will produce enormous economic benefits" (Cheng, 2019, p. 285), and Improved risk allocation strategies (Liu et al., 2021).

Drone photogrammetry and laser scanning. The use of drones in the construction and generally infrastructure industry is numerous. Above all, they enable a new way of using other modern technologies such as laser scanning, 3D modeling and photogrammetry, which benefit greatly from being able to view buildings from the air, allowing for a much more comprehensive view. As far as using drones in PPP projects, Rayi et al. (2019) consider that "the formation of PPPs with private entities that manufacture tethered drones can help the city unfurl the potential of its existing […] and envisioned […] internet

infrastructure and consequently enhance the connectivity sector" (Rayi et al., 2019) Additionally, they can also increase cost-efficiencies for all stakeholders (Meinig et al., 2019).

Starting from the above-mentioned digitalization technologies in infrastructure and construction PPP projects, an analysis of current and future trends in PPPP projects will be drawn.

The following hypotheses will be tested:

H1: There is a positive relationship between BIM technology and PPP projects.

H2: There is a positive relationship between Automation and Robotics and PPP projects.

H3: There is a positive relationship between Artificial Intelligence and PPP projects.

H4: There is a positive relationship between Drone photogrammetry and laser scanning and PPP projects.

Methodology

In terms of methods, two types are being used: time series analysis and a survey. Thus, the research is based on the results of a survey conducted among public and private authorities involved in PPP projects in 6 European states in order to draw a comparative perspective. The survey focused on digital technologies in infrastructure and construction PPP projects, the respondents being asked to determine the opportunity of Industry 4.0 in PPP projects. Before proceeding with the survey analysis, time series analysis will be used for the selected countries. Thus, in Table 1 is presented an overview of previous experiences with PPP projects in the scrutinized states.

Table no. 1. PPP overview, by analyzed countries between 2012-2020

	Number of projects, 2012-2020	Total value of projects, EUR bn, 2012-2020
France	124	21.1
Germany	50	8.9
Italy	18	9.6
Romania	N.D.	N.D.
Bulgaria	1	0.9
United Kingdom	149	31.3
Total	342	71.8

Source: Authors' analysis and EPEC (2023a). Evolution of the PPP market; Available at: https://data.eib.org/epec/sector/all, accessed on 13.11.2023.

The countries with the biggest experience in PPP projects from the ones selected are: United Kingdom, France and Germany, respectively developed countries. The three of them have large experience with various PPP projects (see in this vein Table 2) and the biggest part of value of conducted PPP projects in these states was used in infrastructure and constructions.

Table no. 2. PPP overview, by sector in the analyzed countries between 2012-2020

	Transport	Environment	Education	Public order and safety	Recreation and culture	General public services	Defense	Health care	Housing and community services	Telecommunications
France	21	13	34	6	15	3	1	5	5	21
Germany	12	20	4	4		6		3	1	
Italy	5	1	2		1			9		
Romania	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Bulgaria	1									
United Kingdom	12	24	61	4	2		1	33	12	

Legend: ND- No data available.

The data series provided by EPEC have a yearly frequency, cover the time interval 2012-2020 and were provided by the EPEC website. The selection of the European states was made after taking into consideration the available respondents involved in PPP projects. Data were not obtained for Romania from EPEC, but since there were respondents from this country, the state was not excluded from the analysis.

The survey covered both respondents from public institutions and private companies. The primary condition for participation in the survey was being previously or currently involved in a PPP project. Therefore, only professionals in the implementation of Industry 4.0 in the construction/infrastructure industry, were involved through an online questionnaire. This online questionnaire was preferred because of the geographical spread of the 6 countries in Europe. The survey took place between the 1st May 2023 and the 1st June 2023, being sent via email in a link.

Results and Discussion

The respondents' attitudes were analyzed in relation to four major themes: BIM-enabled PPP project (BP), Automation and Robotics in PPP projects (ARP), Artificial Intelligence in PPP projects (AIP) and Drone photogrammetry and laser scanning in PPP projects (DP). The results indicate that there are significant differences in respondents' views regarding the adoption of Industry 4.0 in PPPP projects. The results, presented in Figure 2, reflect that respondents are willing to cooperate with other parties in BIM-enabled PPP projects. Out of 469 respondents, the strongest agreement was obtained from United Kingdom (100.0% agree and strongly agree with the item) followed by France (96.0%) and Germany (89.3%), therefore from developed countries. Further on, respondents from Italy agreed and strongly agreed (63.8%) to cooperate with other parties in BIM-enabled PPP project, followed by respondents from Bulgaria (52.4%) and Romania (51.8%). What can be seen is the neutral score, very high for Romania (29.80%), Bulgaria (27.60%) and even Italy (25%). However, in spite of their different experiences with BIM-enabled PPP project (BP), the respondents from all countries would choose to cooperate with other parties in BIM-enabled PPP project. The results can be seen in Figure 2:

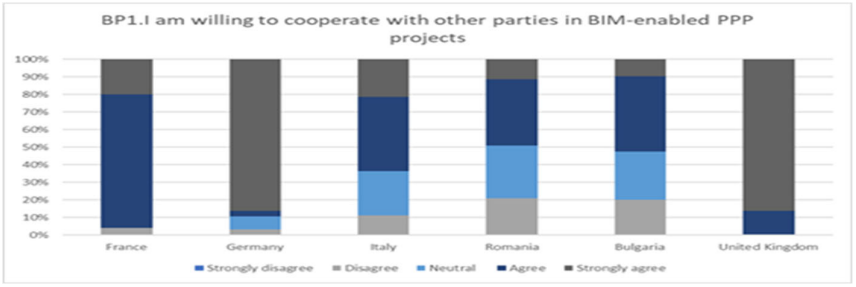

Figure no. 2. BP1.I am willing to cooperate with other parties in BIM-enabled PPP projects. Countries' perspective
Source: authors' analysis based on survey

Out of 469 respondents in 6 analyzed European countries, 30.5% Agree and 48.6% Strongly agree that successful PPP projects use BIM technology, therefore a total of 79.10% Agree and Strongly agree with this affirmation (see Figure 3).

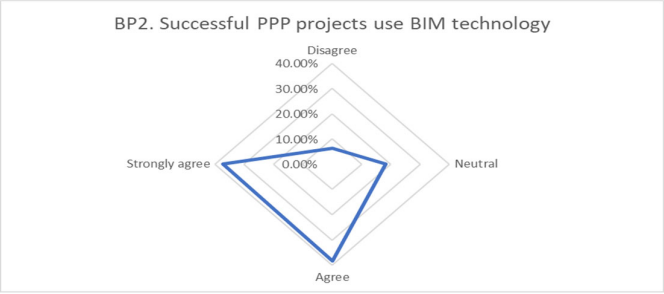

Figure no. 3. BP2. Successful PPP projects use BIM technology
Source: authors' analysis based on survey

As far as Automation and Robotics in PPP projects is involved, there is a tendency of moving from Strongly Agree to Agree (55%) of most respondents, as compared to the previous items concerning BIM-enabled PPP projects. This tendency can be seen in Fig. 4:

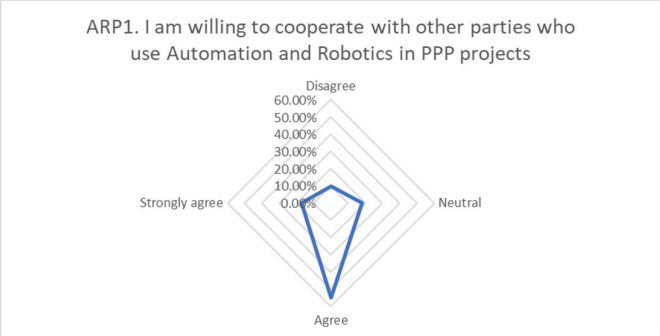

Figure no. 4. ARP1. I am willing to cooperate with other parties who use Automation and Robotics in PPP projects

Source: authors' analysis based on survey

The last two items concerning Drone photogrammetry and laser scanning in PPP projects increase further more the disagreement of respondents. Thus, for item 2: DP2. Successful PPP projects use Drone photogrammetry and laser scanning 55.5% Strongly agree and Agree with the AIP1, while 10% are Neutral and 34% Disagree and Strongly disagree. Figure 12 confirms this attitude:

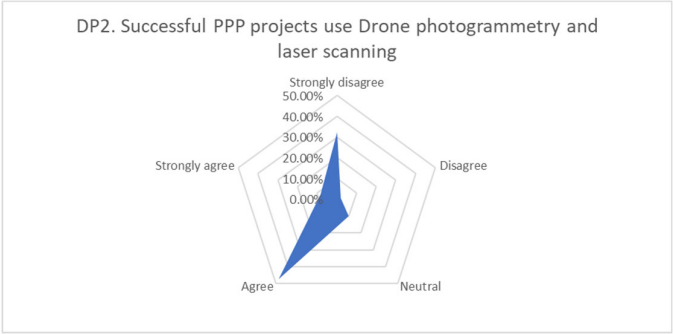

Figure no. 5. DP2. Successful PPP projects use Drone photogrammetry and laser scanning

Source: authors' analysis based on survey

Interpretation

An interesting result is that the attitudes of respondents had a bigger tendency towards Strongly agree and Agree for the first theme, tendency which started to decrease slowly for the next themes. Thus, for the first theme, in spite of their different experiences with BIM-enabled PPP project (BP), the respondents from all countries would choose to cooperate with other parties in BIM-enabled PPP projects. Also, for the second item, in analyzing the results of the survey across countries it can be seen that more than 50% respondents from the selected countries Strongly agree and Agree that successful PPP projects use BIM technology: France (100.0%), Germany (100.0%), United Kingdom (100.0%), Italy (83.7%), Romania (69.3%) and Bulgaria (52.4%). Also, for the third item more than half of survey participants Agree and Strongly agree with it. A total of 75.50% Agree and Strongly agree with this affirmation, again UK, Germany, France and Italy leading, followed by Romania and Bulgaria. This confirms the hypothesis according to which "H1: There is a positive relationship between BIM technology and PPP projects." In addition, the results confirm that motivation for the adoption of BIM is very high in UK (Early adopter), Germany, France and Italy (Late adopters), decreasing in Romania and Bulgaria, which are indeed Very late adopters of BIM techniques in PPP projects. Also, it was observed that respondents from Romania and Bulgaria have a bigger tendency to Disagree or be Neutral regarding the first three items related to BIM-enabled PPP project (BP). This confirms that, being Very late adopters, these countries are still considering BIM techniques in PPP projects, their awareness not being very high.

For the second theme, Automation and Robotics in PPP projects (ARP), there is a tendency of moving from Strongly Agree to Agree (55%- ARP1) of most respondents, as compared to the previous items concerning BIM-enabled PPP projects. In spite of these, more than half of the respondents Agree with these two items, which confirms the hypothesis: "H2: There is a positive relationship between Automation and Robotics and PPP projects."

The next four items focused on Artificial Intelligence (2) and Drone photogrammetry and laser scanning (2) in PPP projects. Taking into account that AI is on its' way of being regulated, therefore, many aspects are still not very well determined, the respondents continue to be more and more neutral or even in disagreement with the items, in this second part of the research. In spite of this, more than half of the respondents are willing to cooperate with other parties who use Artificial Intelligence in PPP projects. Thus, the third hypothesis is also confirmed: "H3: There is a positive relationship between Artificial Intelligence and PPP projects." According to the last two items concerning Drone photogrammetry and laser scanning in PPP projects, respondents consider that Drone photogrammetry and laser scanning are a must for a PPP project to be successful, although to lesser degree than other techniques. The fourth hypothesis is confirmed: "H4: There is a positive relationship between Drone photogrammetry and laser scanning and PPP projects."

Although, it is significantly lower than in the case of the other themes, Drone photogrammetry and laser scanning have their contribution in PPP projects, recognized by the respondents. Actually, a proper PPP project managed in BIM also includes a 3D model of the entire building - its terrain model being realized using photogrammetry technology from a drone (Antwi-Afari et al., 2018).

Conclusions

More than half of the respondents were in favour of (1) BIM-enabled PPP projects (BP), (2) Automation and Robotics in PPP projects (ARP), (3) Artificial Intelligence in PPP projects (AIP) and (4) Drone photogrammetry and laser scanning in PPP projects (DP). The research highlights that both the state and the private companies must adapt and therefore invest in technology so as to optimize the adoption of Industry 4.0 in PPP projects, in order to increase the success of PPP projects. Survey result shows that, depending on the country, every half of the respondents support Industry 4.0 in relation to PPP projects. This is important since the research results have shown that all respondents no matter from which country they are, are open to adoption of Industry 4.0 in PPP projects, particularly in construction and infrastructure.

The limitations of the study imply that, the researcher did not consider countries that were not from Europe. In addition, only respondents from 6 countries from Europe were surveyed, so a bigger number of states/respondents could also be used. Also, only construction and infrastructure were taken into account, so other industries could also be analyzed. Future research could investigate different countries and even different cohorts, such as Millennials, Generation X/Generation Z, in order to expand the comparative perspective. In addition, they could focus on qualitative research, to complement the current results, or even o case studies from various countries.

The result of this work can serve primarily the professionals involved in this topic and looking for more detailed and objective statistics on PPP projects, which can be used for more detailed analyzes and, where appropriate, for the implementation or modification of strategies.

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