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Advancing BIM and Sustainability with Coopetition: Evidence from the Portuguese Stone Industry

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Abstract: The construction industry, a vital sector of the global economy, is projected to grow significantly over the next 15 years. Despite its importance, this industry struggles with inefficiency, high costs, prolonged timelines, and substantial ecological impacts. These challenges have led governments to advocate for Building Information Modeling (BIM) to enhance Efficiency and sustainability through comprehensive digital representations of physical and functional characteristics. The effective integration of BIM technology hinges on the active participation of industry providers, raising the question of how these providers can positively contribute to improving BIM dimensions. This study investigates the potential of coopetition networks within the Portuguese Ornamental Stone industries (OS-PT) to address this challenge. Coopetition networks, which blend competition and cooperation, foster collaborative networks among companies to enhance their response to digital supply chains. The research employs an Experimental Pilot Network facilitated by an Industrial Internet of Things (IIoT) artefact to assess the benefits of coopetition networks. The findings demonstrate that transitioning from current practices (CB.P) to coopetition network practices (CN.P) significantly improves operational Efficiency, labour productivity, and sustainability. Specifically, the transition resulted in a 15.6% increase in on-time delivery performance, a 27.38% improvement in labour productivity, and a 21.8% reduction in CO_2 emissions per part produced. These improvements align with Sustainable Development Goals (SDGs) 8, 9, 11, and 13, highlighting the strategic value of coopetition in driving innovation and sustainability in the construction industry. Future research should explore the scalability of these findings across different sectors and further refine methodologies to maximize the benefits of coopetition networks.

Keywords: coopetition; construction industry; BIM; ornamental stone; sustainable development goals

1. Introduction

The construction industry is a cornerstone of the global economy, with projected growth expected to exceed US$4.2 trillion over the next 15 years [1]. Despite its significance, the industry faces persistent challenges, including inefficiency, high costs, prolonged timelines, and substantial ecological impacts [2]. These issues have prompted governments to advocate for adopting Building Information Modeling (BIM), which promises to enhance Efficiency and sustainability in construction by creating comprehensive digital representations of physical and functional characteristics [3].

Government initiatives have spurred the integration of BIM technology, aiming to transform it into a global digital supply chain [4]. However, the positive impact of BIM in the construction industry depends on the positive contribution from industry providers [5]. This raises the question: How can construction industry providers positively contribute to improving BIM dimensions?

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A promising approach to this challenge is the concept of coopetition networks [6], which combines elements of competition and cooperation [7]. By fostering collaborative networks among companies, coopetition enhances responses to digital supply chains [8].

This study explores the potential of coopetition networks within the Portuguese Ornamental Stone industries (OS-PT). Specifically, it investigates how transitioning to coopetition networks can enhance the sector's response to BIM dimension demands.

To address this challenge, the investigation will be conducted through an Experimental Pilot Network facilitated by an Industrial Internet of Things (IIoT) artefact. The project involves selected enterprises in the OS-PT industry and will assess the tangible benefits of these networks. Additionally, it will evaluate their alignment with Sustainable Development Goals (SDGs) [9].

2. BIM as a Response to a Sustainable Construction Industry

The traditional management in the construction industry has been criticized for generating avoidable waste, reflected in high costs, extended project timelines, and significant ecological footprints [10]. In response, governments and industry practitioners have supported the gradual implementation of BIM to increase transparency and Efficiency [4].

BIM has evolved as a successor to CAD in the construction industry [11]. Driven by government directives, the construction industry is now at the forefront of incorporating BIM into its practices, motivated by cost reduction goals, shortened project timelines, and alignment with sustainability principles [12]. This integration signifies a significant shift towards more responsible and efficient design and construction methodologies [13].

BIM represents a paradigm shift in conceptualizing, executing, and managing construction projects. At its core, it provides a digital twin of physical construction [14].

The essence of BIM technology lies in creating a digital representation that mirrors every facet of physical construction [15]. However, this has led to some confusion in the industry regarding the conflation of BIM maturity with its dimensions [16]. BIM maturity refers to the sophistication level at which the supply chain can exchange information, highlighting the collaborative capabilities of the involved parties. In contrast, BIM dimensions encompass the various data types attached to a model, adding depth and insight into the project's lifecycle [17].

Incorporating data dimensions within a BIM context allows for unparalleled comprehension of the construction process [18]. Designers and stakeholders gain a holistic view of the project, including initial design, work stages, delivery methods for each component, budgeting, and maintenance plans. These dimensions foster a more refined management approach.

The fourth (4D) BIM dimension integrates the crucial aspect of time, marking a significant evolution in project management and coordination within the construction industry. By incorporating project timelines directly into BIM models, 4D BIM introduces a dynamic, interactive approach to planning, allowing for real-time visualization of construction sequences [11]. The fifth (5D) BIM focuses on cost management within construction projects by integrating financial data with each component in the digital model. This holistic approach transforms budgeting into a dynamic, detail-oriented process, enabling immediate visibility and ongoing updates on the financial impacts of design choices and manufacturing changes throughout the project's duration [19]. Moreover, the sixth (6D) BIM dimension focuses on sustainability by integrating environmental sustainability metrics directly into the building information model [20]. This approach prioritizes the ecological footprint of materials and processes throughout a project's lifecycle, equipping professionals with the tools to make decisions that adhere to sustainability objectives [21].

However, to realize the full potential of BIM, construction providers must effectively address, contribute to, and enhance each BIM dimension [22]. The positive impact of BIM in the construction industry thus depends on the active and practical contributions from industry providers [5].

3. Theoretical Background

The concept of "coopetition," was initially introduced into the strategic management lexicon by Ray Noorda, the founder and CEO of Novell, during the 1980s [23]. It gained prominence in business strategy through the influential work of Nalebuff and Brandenburger (1997), which marked a significant shift in understanding competitive dynamics [24]. Over the years, coopetition has garnered substantial attention within strategic management, evolving through various interpretations and applications [25].

Despite its widespread discussion, the definition of coopetition remains varied, with interpretations spanning different goals, relationships, and organizational contexts [26]. It has been described as a strategy that encompasses the simultaneous pursuit of cooperation and competition among firms, a hybrid activity within the same business entities, and a complex interplay that affects competitive dynamics among different market players [7].

At the nexus of coopetition and networks, a strategic orientation centred around innovation emerges, essential for firms seeking to bridge competitive gaps and effectively manage market challenges [27]. This orientation emphasizes coopetition's role in navigating competitive terrains and highlights its potential as a catalyst for transformative growth and resilience [28]. Studies show a wide range of findings, underscoring the need for a more unified and in-depth exploration of value co-creation processes in these complex networks [29].

A comprehensive review by Meena, Dhir, and Sushil (2023) reveals that coopetition has been examined through various theoretical lenses such as Game Theory, Resource-Based View, Paradox Theory, Transaction Cost Theory, and Network Theory. Each perspective, while insightful, often addresses the concept within its specific confines [25]. Regardless of the diversity in definitions, the essence of coopetition converges on the notion of a hybrid relationship where competition and collaboration intertwine to benefit the involved companies [30]. It is particularly relevant in digital supply chains [28].

In conclusion, coopetition networks represent a strategic paradigm where the dual forces of cooperation and competition are harnessed to foster innovation, enhance competitive advantage, and achieve collective success [7]. This dynamic interplay seems interesting for navigating the complexities of modern digital supply chains and addressing the evolving challenges of the construction industry.

4. Methodology

The case study method is invaluable for examining the interface between a phenomenon and its context. It offers a structured approach for event analysis, data collection, and result reporting [31]. This methodology allows researchers to deeply understand the underlying reasons and identify potential future research directions related to the studied instance [32].

To quantitatively assess the contribution of a coopetition network in enhancing BIM dimensions, the Coopetition Experimental Pilot Network (CEPN) is implemented through the following sequential steps:

Selection of Participants: Identify and select SMEs that meet specific criteria for participation.

Network Formation and Metrics: Integrate the IIoT to connect the selected SMEs to facilitate real-time data collection and analysis.

Establish the coopetition network by integrating IIoT to connect the participating SMEs, focusing on collaboration and resource sharing, and defining relevant metrics and KPIs.

Data Collection: Gather data on KPIs related to BIM dimensions, such as time response, cost efficiency, and carbon reduction.

This structured methodology provides a systematic approach to exploring the effects of coopetition networks on the construction industry SMEs, offering insights on how construction industry providers can contribute positively to improving the BIM dimensions.

4.1. Selection of Participants

The OS-PT sector, a cornerstone of Portugal's rich cultural heritage and forward-looking innovation, has significantly contributed to iconic stone monuments worldwide since the 15th century [33]. Leveraging Portuguese stone, engineering prowess, and generations of accumulated expertise, the OS-PT sector is deeply woven into the fabric of the nation's identity. As the 21st century progresses, Portugal has solidified its position as a leading producer of stone products, skillfully integrated into the global construction industry, a testament to its competitive edge on the international stage despite the country's modest geographic footprint [34].

Portugal's ornamental stone industry, characterized by its vast and varied stone reserves, plays a crucial role in the global market. The shift towards digital collaborative efforts with customers and architects worldwide underscores a dynamic evolution; the sector's traditional strengths are being purposed through innovation [35]. This emerging digital engagement, though still developing, is pinpointed as a critical growth avenue for Portuguese stone providers.

According to the Portuguese Stone Federation (2022), the OS-PT sector exports to 116 countries, ranks as the ninth most significant player in the World International Stone Trade and secures the second position globally regarding international trade per capita. With exports outstripping imports by 660% and a significant share of exports reaching markets outside Europe, the industry boasts a turnover of €1.230 million. It supports over 16,600 direct jobs, making it a critical employment source, particularly in inland regions [34].

According to some authors [36], OS-PT companies can enhance their global competitiveness and sustainability by integrating digital technologies into their processes, ensuring their rich heritage continues contributing to contemporary architectural and construction projects worldwide [37].

However, this requires construction industry providers to respond positively to BIM dimensions, specifically regarding time response, price, and carbon reduction [34]. Due to their limited financial capacity as SMEs [38], achieving these goals is only possible through collaboration [39].

A cooperation network can be the solution here, though it requires a concrete evaluation of its response to BIM dimensions.

The strategic implementation of the CEPN began by establishing direct and informal communication channels with the managing directors of potential participant companies, who were then formally invited to participate in the study. A comprehensive confidentiality agreement was drafted to protect sensitive information regarding the companies' operations, clientele, employees, resources, and competitors.

The selection process involved an initial assessment of current best practices (CB.P) and a data collection phase after implementing the CEPN among OS-PT SMEs engaged in coopetition network practices (CN.P).

The project's oversight has been enforced to maintain data integrity and confidentiality. It was achieved through direct, daily monitoring and recording of quantitative data using digital machinery and databases, safeguarding the accuracy and privacy of the collected data. The process began with a baseline assessment of CB.P within the participating SMEs, then systematically capturing the change dynamics under CN.P and documenting their immediate impacts.

4.2. Coopetition Network Formation and Metrics

The emergence of the IoT marks a transformative era, significantly influencing ecosystems through sophisticated sensor technologies that enhance connectivity and data exchange [40]. Building on traditional IoT frameworks, IIoT introduces intelligence to industrial settings, facilitating direct device-to-device communication and supporting the creation of intelligent artefacts that dynamically adapt to user interactions and enhance value co-creation [41]. Empirical evidence highlights the transformative potential of IIoT-based innovations in fostering novel service offerings such as remote control and predictive maintenance solutions [42]. These capabilities advance operational Efficiency and open new avenues for value co-creation within coopetition frameworks, expanding service portfolios and enhancing enterprises' competitive and cooperative capacities [43].

An example in the OS-PT sector is an IIoT artefact, developed through the Inovstone4.0 R&D Project (Silva, Rabadão et al., 2020). This IIoT system has transformed the connectivity of ornamental stone processing SMEs with the digital market, notably through its 'fingerprint4.0' functionality (Silva, Gil, et al., 2020), which refines product specifications and promotes value co-creation between providers and customers, improving customization and operational productivity [45].

Cockpit4.0 epitomizes the IIoT's capacity to redefine market dynamics through direct engagement and collaborative efforts. As a state-of-the-art system, it is an excellent starting point for transforming the operational technology that facilitates competition in the Experimental Pilot Network. It is a dynamic enabler of cyber value propositions, enhancing service delivery and operational competitiveness among SMEs [46].

To further harness this potential, new functionalities were added to Cockpit4.0, enabling secure connections between competing firms. A more advanced version, Cockpit4.0+, was developed as part of this research. This new IIoT artefact was specifically created to connect rival SMEs within the OS-PT sector in a coopetition network. This enhancement advances technological capabilities and fosters a collaborative industrial environment conducive to shared innovation and strategic growth involving the shop floor.

Embedding OPC-UA protocols [41], Cockpit4.0+ bridges gaps in connectivity, Efficiency, and responsiveness, fostering an ecosystem where SMEs thrive through collective innovation and adaptive strategies. Cockpit4.0+ integrates technological innovations like artificial intelligence to promote a collaborative industrial environment, ensuring sustainable operations and maintaining SMEs' competitiveness in a dynamic market.

Once the Cockpit4.0+ prototype was developed, the implementation of the coopetition network formation began. To this end, three selected companies, recognized as leaders in the Portuguese stone sector, were formally connected (Figure 1). All their machines are connected to the ERP system, which connects to BIM architects' stations. This setup represents the OS-PT sector's CB.P. A comprehensive confidentiality agreement was drafted to protect sensitive information regarding the companies' operations, clientele, employees, resources, and competitors.

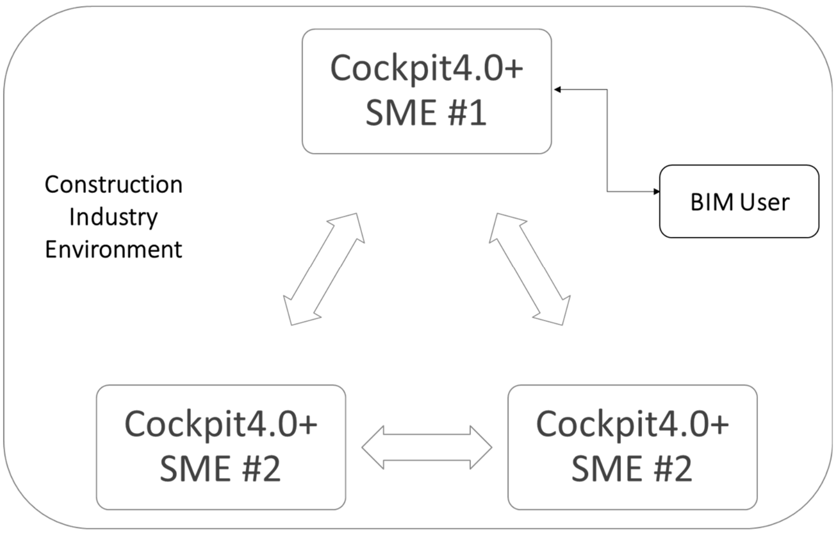

Figure 1. Experimental Pilot Network (CEPN).

The 4D BIM dimension, which integrates the crucial aspect of time, represents a significant advancement in project management and coordination within the construction industry [11]. By making the project timeline accessible and comprehensible to all stakeholders, 4D BIM promotes transparency, accountability, and more effective communication [47]. To effectively respond to the 4D BIM dimension, construction industry fabricators must enhance their scheduling, coordination, and productivity processes.

The On-Time Delivery (KPI_{OtD}) evaluates the stone fabricators' responses to 4D BIM requirements, reflecting their ability to meet project deadlines consistently (Equation (1)). In the CEPN, the KPI_{OtD} measures the percentage of stone parts delivered within the agreed timeframe reflecting operational Efficiency and reliability of the OS-PT SMEs. Improvements in KPI_{OtD} directly enhance the effectiveness of 4D BIM by ensuring timely project execution and adherence to schedules.

$$KPI_{OtD}\ (\%) = \sum_{1}^{54}\left(\frac{parts\_delivered\_on\_time_{(daily)}}{parts\_delivered_{\ (daily)}}\right) \tag{1}$$

In the CEPN, the KPI_{OtD} measures the percentage of stone parts delivered within the agreed timeframe, reflecting the operational Efficiency and reliability of the OS-PT SMEs. Improvements in KPI_{OtD} directly enhance the effectiveness of 4D BIM by ensuring timely project execution and adherence to schedules.

The 5D BIM dimension integrates cost data with the 3D model, enabling comprehensive budget and financial management throughout the project lifecycle [19]. This integration helps optimize resources, including labour, for cost efficiency and project success. The KPI - Labor Productivity (KPI_{LP}) measures the number of parts or tasks a worker completes within a specified timeframe, indicating the Efficiency of labour use. By focusing on labour productivity improvements, fabricators can ensure they are meeting the demands of 5D BIM (Equation (2)). By using KPI_{LP} in the CEPN, fabricators can monitor and enhance labour efficiency, ensuring that they align with the cost management goals inherent in the 5D BIM dimension. This focus on productivity supports budget adherence and contributes to overall project success.

$$KPI_{LP}\ (\%) = \sum_{1}^{54}\left(\frac{parts\_produced_{(daily)}}{workers\_involved_{(daily)}}\right) \tag{2}$$

The 6D BIM dimension focuses on sustainability by incorporating environmental data into the BIM model to manage and reduce the ecological footprint of construction projects [21]. This integration helps assess and optimize the environmental impact of building materials, construction processes, and the overall project lifecycle.

The CO2 Equivalent (CO2-eq) factor converts the energy consumed into equivalent carbon dioxide emissions, providing a standardized measure of environmental impact. According to the European Electricity Review (2023), the carbon intensity of electricity in Europe varies significantly among different EU member states due to the diverse energy mixes. For example, countries like Sweden and France have much lower carbon intensities (below 50 g CO_2/kWh) because of their heavy reliance on nuclear and renewable energy sources [48]. On the other hand, countries like Poland and Estonia have higher carbon intensities (over 600 g CO_2/kWh) due to their dependence on coal and other fossil fuels. As of 2022, the average carbon intensity of electricity generation in the EU was around 276 grams of CO_2 per kilowatt-hour (g CO_2/kWh).

By evaluating carbon emissions about the number of parts produced, companies can identify inefficient production processes that lead to higher energy use and emissions. Tracking the KPI for CO2 Equivalent ($KPI_{CO2\text{-}Eq}$) over time helps companies set benchmarks for sustainability performance, identify trends, and implement improvements to reduce their carbon footprint (Equation (3)).

$$KPI_{CO2\text{-}eq}\ (KgCO2/part) = \sum_{1}^{54}\left(\frac{energy\_consumed_{(daily)}}{parts\_produced_{(daily)}}\right)\ x\ 0.276 \tag{3}$$

In the CEPN, $KPI_{CO2\text{-}eq}$ measures the amount of CO2 emissions associated with the production of each stone part, indicating the project's environmental Efficiency. Reductions in $KPI_{CO2\text{-}eq}$ directly impact the construction industry's contributions to SDGs, particularly SDG 11: Sustainable Cities and Communities, by promoting environmentally responsible practices and reducing urban carbon footprints.

4.3. Data Collection

This study employed a data collection strategy across two fifty-four-day intervals to explore the transition from CB.P to CN.P enhanced by the CEPN, enabling a robust comparative analysis of operational outcomes.

Phase 1 - CB.P: The first interval, which concluded on June 10th, 2023, focused on capturing standard operations at three anonymized companies, designated as "A," "B," and "C." This baseline phase documented each company's reliance on internal resources for production and delivery, providing essential reference data for subsequent comparisons.

Phase 2 - CN.P: The second interval, which concluded on November 14th, 2023, assessed the effects of integrating these entities into a CEPN-enhanced coopetition-based network. This phase represented a significant shift by fostering coopetition interactions and shared use of technologies and resources, moving beyond standard practices.

Data management and privacy were maintained throughout the study in compliance with confidentiality agreements. All data were anonymized and referred to only by company labels. Data collection, recording, and exportation procedures were meticulously followed, with results exported to Excel files as detailed in the methodology section. It ensured a secure and consistent approach to data handling, enabling detailed analysis while safeguarding the privacy and proprietary information of the participating companies. This structured methodology facilitated a direct comparison of operational outcomes and upheld the integrity and confidentiality of the data throughout the research process.

5. Results: Evaluating the Practices of Construction Industry Providers

Tables 1 and 2 summarize the average findings derived from data collected under CB.P and CN.P from the three selected SMEs. These tables provide a consolidated view of the metrics under each set of practices, offering a comprehensive analysis of operational scale determinants within the SMEs.

Table 1. Summary of Average Data Collected Under CB.P.

Data ID	Description	Current Practices (CB.P)	Data (average daily)
Data 1	Parts delivered	∑ parts_delivered	339
Data 2	Parts delivered on time	∑ parts_delivered_on_time	240
Data 3	Parts Shipped	∑parts_shipped	338.5
Data 4	Labours Involved (h)	∑labour_involved	49.3
Data 5	Energy Consumed (kWh)	∑energy consumed producing parts	4692
Data 6	Parts Produced	∑parts_produced	369.9

Table 2. Summary of Average Data Collected Under CN.P.

Data ID	Description	Coopetition Practices (CN.P)	Data (average daily)
Data 7	Parts delivered	∑ parts_delivered	454
Data 8	Parts delivered on time	∑ parts_delivered_on_time	358
Data 9	Parts Shipped	∑parts_shipped	415.8
Data 10	Labours Involved (h)	∑labour_involved	49.3
Data 11	Energy Consumed (kWh)	∑energy consumed producing parts	4071
Data 14	Parts Produced	∑parts_produced	416

Using the data collected, the KPIs were assessed, and average results were compiled, as depicted in Table 3.

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Table 3. Comparative Assessment of BIM-Related KPIs for CB.P and CN.P.

Key Performance Indicators (KPIs)	CB.P	CN.P	Quantitative Gain
KPI - On-Time Delivery (parts/parts)	0.671	0.775	15.6%
KPI - Labor Productivity (parts/worker)	6.84	8.72	27.38%
KPI - CO2-eq (KgCO2/part)	3.41	2.68	21.8%

The results demonstrate significant improvements in on-time delivery, labour productivity, and carbon efficiency under CN.P compared to CB.P. These findings highlight the potential benefits of implementing coopetition networks in SMEs, suggesting that such collaborative efforts can lead to enhanced operational performance and sustainability.

6. Discussion on Enhancing BIM Dimensions through Coopetition Practices

This section discusses the findings and evaluates how cooperative practices can improve BIM dimensions. The analysis focuses on interpreting the results to identify cooperative strategies and responses that positively impact BIM practices within the construction industry.

6.1. Responding to 4D BIM: Enhancing On-Time Delivery through Coopetition Practices

The 4D BIM dimension integrates the crucial aspect of time, significantly evolving project management and coordination within the construction industry. **Under CB.P**, the on-time delivery performance was recorded at 67.1%, with 240 out of 339 parts delivered as scheduled. **The CN.P** significantly increased the on-time delivery ratio to 77.5%, with 358 out of 454 parts delivered on time. This improvement highlights CN.P's efficacy in ensuring more reliable customer deliveries.

Figure 2 depicts the trend in on-time delivery performance over 54 days. The data points represent the percentage of deliveries made on time each day, offering insights into the consistency and reliability of delivery services over the observed period.

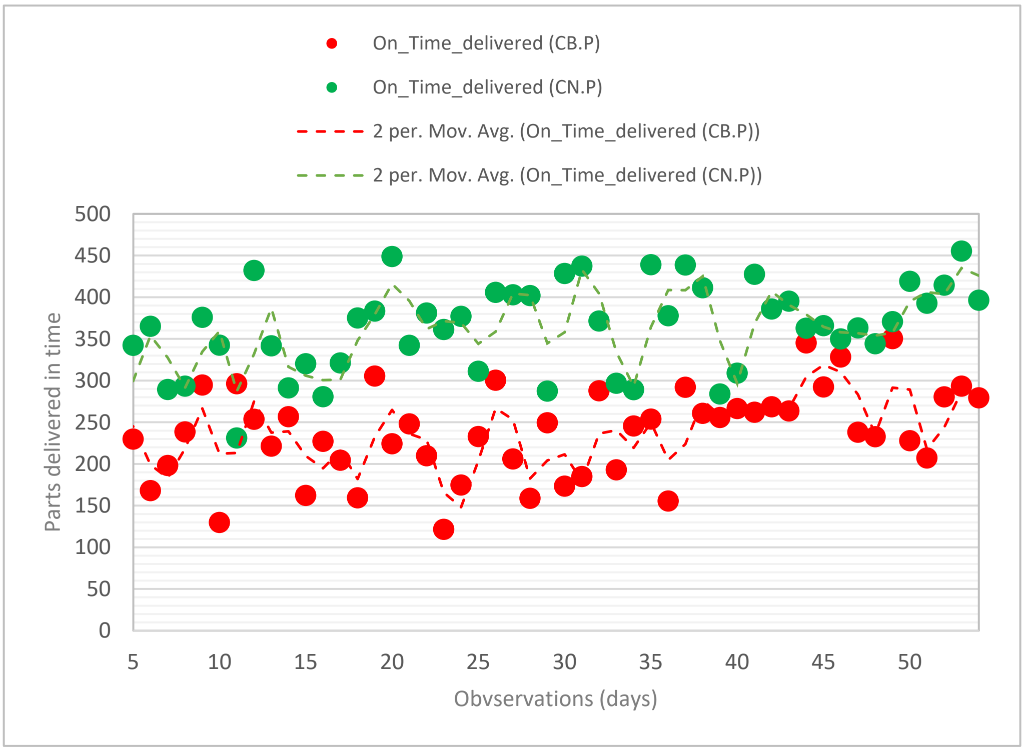

Figure 2. Trend in On-Time Delivery Over 54 Daily Observations.

From these results, the OS-PT sector experienced substantial improvements in on-time delivery performance by transitioning to a coopetition network. The increase from 67.1% to 77.5%

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demonstrates how cooperative networks enhance operational Efficiency and reliability, which are critical components of the 4D BIM dimension. This improvement reflects better adherence to project schedules and positively impacts customer satisfaction, illustrating the benefits of collaborative strategies in meeting 4D BIM requirements.

6.2. Responding to 5D BIM: Enhancing Labor Productivity through Coopetition Practices

The 5D BIM dimension integrates cost data with the 3D model, enabling comprehensive budget and financial management throughout the project lifecycle. **Under CB.P**, employing an average workforce of 49.9, the OS-PT companies managed a daily shipment of 338.5 parts, establishing a labour productivity rate of 6.84 parts per worker. Implementing CN.P enhanced daily output of 415.8 parts while maintaining the same workforce size. It boosted the labour productivity rate to 8.72 parts per worker, a significant uptick that showcases the positive ramifications of coopetition on labour efficiency.

Figure 3 displays daily labor productivity over 54 days. Each data point represents the productivity level for a given day, measured to assess performance trends and variations. The figure aims to highlight patterns in productivity, helping to identify days with higher or lower Efficiency and providing insights for potential operational improvements.

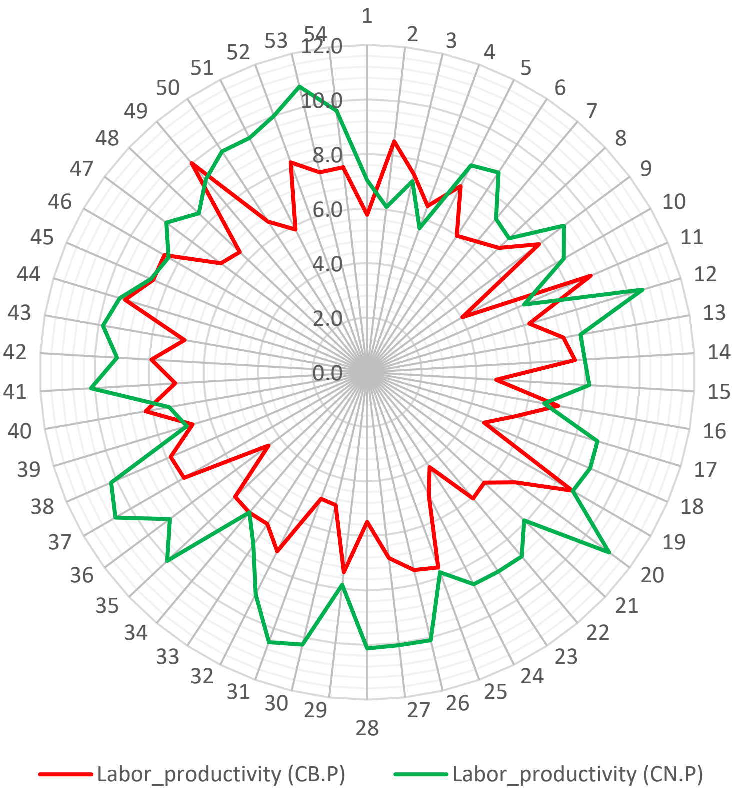

Figure 3. Daily Labor Productivity Across 54 Observations.

By adopting coopetition practices, the OS-PT SMEs were able to optimize their labour resources more effectively. This improvement in labour productivity, from 6.84 to 8.72 parts per worker, highlights how collaborative strategies can enhance operational Efficiency and cost management. As a result, fabricators can better meet the demands of the 5D BIM dimension, ensuring that projects are completed within budget and on time, ultimately leading to enhanced project outcomes and greater competitiveness in the market.

6.2. Responding to 6D BIM: Enhancing Sustainability through Coopetition Practices

The 6D BIM dimension focuses on sustainability by incorporating environmental data into the BIM model to manage and reduce the ecological footprint of construction projects. Under CB.P, CO2 emissions per stone part produced were recorded at 2.88 Kg CO2-eq. Implementing CN.P significantly decreased CO2 emissions per stone part produced, reducing from 3.41 Kg CO2-eq to 2.68 Kg CO2-eq.

Figure 3 illustrates the CO_2-eq emissions per part produced, measured across 54 consecutive days. The data points highlight the daily emission variations, providing insights into the environmental impact of production processes and identifying trends and areas for potential improvement in reducing carbon footprints.

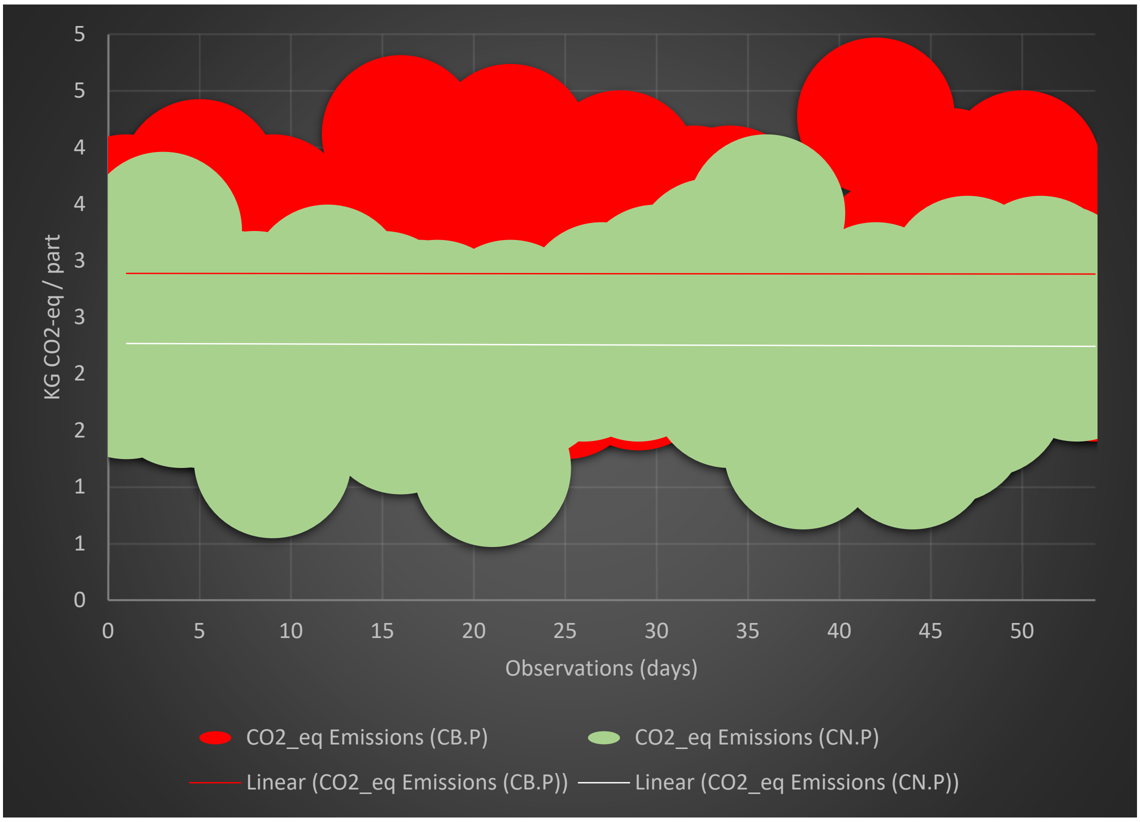

Figure 4. CO_2-eq Emissions per Part Produced Over 54 Daily Observations.

This 21.8% reduction in CO2 emissions highlights the significant potential of coopetition networks to lower the carbon footprint of manufacturing activities. By transitioning to coopetition network practices, the OS-PT sector demonstrated a marked improvement in sustainability performance. The decrease in CO2 emissions per part underscores how collaborative strategies can effectively respond to the 6D BIM dimension by optimizing resource use, reducing waste, and enhancing overall environmental Efficiency. This improvement aligns with sustainability goals and strengthens companies' competitive positioning by showcasing their commitment to reducing environmental impact.

7. Conclusions

This study demonstrates that transitioning from CB.P to CN.P significantly enhances the operational Efficiency, labour productivity, and sustainability of the Portuguese Ornamental Stone industries. The CEPN findings, facilitated by an Industrial Internet of Things (IIoT) artefact, underscore the transformative potential of coopetition networks.

Operational Efficiency (4D BIM): The transition to CN.P improved on-time delivery performance from 67.1% to 77.5%, a 15.6% increase. This enhancement boosts project schedule reliability and customer satisfaction, aligning with SDG 9: Industry, Innovation, and Infrastructure.

Labor Productivity (5D BIM): Daily shipments increased from 338.5 to 415.8 parts, raising labour productivity from 6.84 to 8.72 stone parts per worker, a 27.38% improvement. This optimization of labour resources supports SDG 8: Decent Work and Economic Growth.

Sustainability (6D BIM): CO2 emissions per part produced decreased from 3.41 kg CO2-eq to 2.67 kg CO2-eq, a 21.8% reduction. This significant decrease highlights the potential of coopetition networks to reduce the carbon footprint, supporting SDG 13: Climate Action and SDG 11: Sustainable Cities and Communities.

By transitioning to coopetition network practices, the OS-PT sector achieved substantial gains in Efficiency, productivity, and sustainability, enhancing overall competitiveness and market positioning. These results highlight the strategic value of collaborative practices in driving innovation and sustainability within the construction industry.

Future research should explore the scalability of these findings across different sectors and further refine methodologies to maximize the benefits of cooperation networks. It would help validate and expand the positive impacts of cooperation on achieving SDGs in various industrial contexts.

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