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Integrating Lean, Green, and Industry 4.0 Technologies in MEP Systems: A Systematic Review for Sustainable Construction Practice

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Abstract

The integration of Lean, Green, and Industry 4.0 (I4.0) technologies has emerged as a crucial focus in the pursuit of enhanced efficiency and sustainability in the construction industry. In particular, the Mechanical, Electrical, and Plumbing (MEP) systems, which are fundamental components of modern construction projects, stand to benefit significantly from the application of these advanced frameworks. However, despite the growing body of literature exploring Lean and Green principles as well as I4.0 technologies, the specific intersection of these concepts within MEP construction remains underdeveloped. This paper aims to address this gap by conducting a systematic literature review that critically examines the integration of Lean, Green, and I4.0 technologies in MEP construction. By analysing existing studies and identifying synergies and challenges, this review seeks to provide a comprehensive understanding of the current state of research and to propose pathways for future development in this area.

Keywords
MEP Construction, Lean, Green, Sustainability, I4.0.

1. Introduction

The rapid evolution of Industry 4.0 (I4.0) technologies, combined with an increasing focus on sustainability, has reshaped many sectors, including construction. As the need for more efficient and eco-friendly practices grows, the integration of Lean and Green principles into construction processes, particularly in Mechanical, Electrical, and Plumbing (MEP) systems, has emerged as a pivotal area for investigation. While these approaches offer significant potential to enhance operational performance, the construction industry, in contrast to sectors like manufacturing, has been relatively slow in embracing and applying these innovations. This paper seeks to explore the synergies between Lean, Green, and I4.0 technologies, with a particular focus on their implementation in MEP systems. Through a systematic review of existing literature, the study aims to identify research gaps, evaluate current frameworks, and propose a cohesive approach to integrating these methodologies. By doing so, this review contributes to the advancement of sustainable, technology-driven practices within the construction industry, offering insights that could lead to greater efficiency and environmental stewardship.

2. Research Question

To set up a systematic review methodology the following Literature review question is adopted:

1. Are the lean and green principles adopted in manufacturer and general construction applicable to MEP systems in construction?
2. What tool or method shall be adopted to measure the conformance to lean and green principles in system construction?
3. What are the common and non-common areas for Lean and green initiatives for the Generic dynamic system construction process?
4. To what extent could the most technologically related mechanism, technology of computer-integrated solutions, BIM-integrated construction, Augmented Reality Integration, Automation in construction, and Industry 4.0 technologies contribute to delivering the subject framework?

3. Literature Review Methodology

The formation of theories is facilitated by well-done literature reviews, which also help to close gaps in knowledge where a wealth of research already exists. (Richard T. Watson, 2020). A systematic search should ensure a relatively complete census of relevant literature. It can be gauged that the review is nearing completion when new concepts in the article set are not found. (Richard T. Watson, 2002). The research questions stated in the preceding section have been answered based on a systematic assessment of the existing literature since a literature review entails a methodical, explicit, and repeatable procedure. A systematic literature review (SLR), is a technique that uses a clear, transparent, and explicit approach and several steps to make sure the literature review process is conducted with the necessary rigour and transparency. A systematic literature review entails the following five steps: 1) formulation of the question, 2) Locating the studies,3) study selection and assessment, 4) analysis and synthesis, and 5) reporting and application of the findings. (Denyer, 2009), Being transparent about the systematic review process is important, especially regarding the literature section and the decisions made about using certain search keywords and databases. This is covered in the subsections that follow. The stages of the SLR that were completed, the tools and methods utilized to support each stage, as well as the portion of the article where they are addressed, are depicted and summarized in Table 1.

Table 1. SLR Stages Aims and Reference

	SLR Stages	Aims	Methodology	Via	Reference
1	Formulation of the question	Restatement of the research question	Distil the question from the overall study	Analytical approach	Section#2
2	Locating the studies,	Segregate and Prioritize The studies	Major Electronic Data sources,	-Elsevier(sciencedirect.com) -Emerald(emeraldinsight.com) -Taylor&Francis (T&F)(tandfonline.com) -IEEE (ieeexplore.ieee.org) -Springer (springerlink.com) -Wiley (onlinelibrary.wiley.com) -Inderscience (inderscience.com) -EBSCO (ebscohost.com) -ISI Web of Science (wokinfo.com) -Research Gate(www.researchgate.net) -Google Scholar (scholar.google.com) -University of Derby Library -MDPI Open Access Journals (www.mdpi.com) - Lean Construction Journal (https://leanconstruction.org/resources/lean-construction-journal/) -The International Association for Automation and Robotics in Construction (http://www.iaarc.org)	Section#3.1
3	study selection and assessment	Calsify the last published studies for relevant subjects			

	SLR Stages	Aims	Methodology	Via	Reference
			Research period assignment, Limitations and border, Identifying the Key word or sentences,	Period 2018-2024 Include: Lean, Sustainability /Green, MEP Construction and I4.0 technology Exclude: Circular Economy and Supply chain when related to the subject The possible combination of Lean, Green, sustainability, eco-efficiency, MEP systems, mechanical and electrical systems, Construction, technology, Environmental Value stream mapping (E-VSM) and Industry 4.0	
4	analysis and synthesis	Conduct Analytical and synthesis procedures	Methods determination Classification and Coding	thematic analysis Excel	Section#4
5	reporting and application of the findings	reporting and implementing the results			Section#5

3.1 Locating the Studies

To locate papers pertinent to the review's focus, search terms were taken into account by several publishers. Elsevier(sciencedirect.com), Emerald(emeraldinsight.com), Taylor&Francis (T&F) (tandfonline.com), IEEE (ieeexplore.ieee.org), Springer (springerlink.com), Wiley (onlinelibrary.wiley.com), Inderscience (inderscience.com), EBSCO (ebscohost.com), Research Gate(www.researchgate.net), ISI Web of Science (wokinfo.com), Google Scholar (scholar.google.com), When the same articles keep showing up, the point of saturation has been achieved. The key subjects of the phenomenon under inquiry served as the basis for the search string specifications. The possible combination of Lean, Green, sustainability, eco-efficiency, MEP systems, mechanical and electrical systems, Construction, technology, Environmental Value stream mapping (E-VSM) and Industry 4.0 technologies were thus included in the search terms. This made it possible to define a precise search focus and exclude articles when it was discovered that they didn't mention the inclusion of both phrases or implied a connection between them. In some circumstances, identical items might be found using different search terms. However, a systematic search and selection technique was required to guarantee the thoroughness of the literature review. When the same articles keep choosing to appear, it is said that saturation has been attained. Furthermore, based on the abstracts of the papers,' manual checks' were undertaken on all of the publications that met the search string requirements. This resulted in the removal of papers that did not address the subject. Peer-reviewed publications published in academic journals and proceedings of international conferences were included in the search results, as these sources are the most valuable and reputable for literature reviews. This, along with the search parameters outlined in this section, led to the identification of a final sample of 62 articles that included some combination of Lean, Green /sustainability, MEP System Construction and I4.0 technologies.

3.2 Analysis and Synthesis

Thematic synthesis was deemed the most suitable method for combining the findings from the systematic review of the literature conducted in this study because it is effective at identifying significant recurring themes and uses structured ways of dealing with data within each theme (Elaine Barnett-Page, 2009). The chosen papers were first

divided into six major centric categories for each aspect, as shown in Fig.1. To be deployed, 1)lean, 2)Green/Sustainability, 3)Technologies/I4.0, 4)General Construction, 5)MEP construction and 6)Manufacturing that all must be operationalized, depending on their broad or small-scale nature, Where they were employed to identify communal characteristics across the literature, the articles categorized in overlapping concept as shown in the article scope matrix Table 2, for example, the same article could be available in more then one category this is to facilitate the concept of centric category, the Analysis and Synthesis of the articles as indicated in the next section 4, the article number will follow Table 2 numbering.

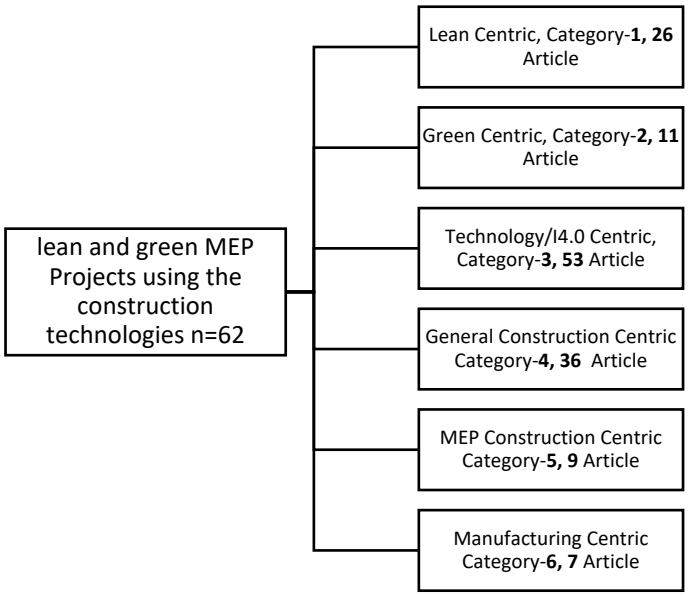

Figure 1. Initial thematic categorization for included articles

With the use of this preliminary categorization, the 62 articles could be coded, individually examined and assigned to one of the classification groups. As a result, lean and green MEP Projects using construction technologies, as well as relevant components and connections between the themes, were found. Figure 1 displays the number of articles that were divided into each category.

Table 2. Article Scope Matrix

#	Author	Lean,	Green	Technology/I4.0	General Construction	MEP Construction	Manufacturing	#	Author	Lean,	Green	Technology/I4.0	General Construction	MEP Construction	Manufacturing
1	(Qinglin Wu, 2022)			X		X		**32**	(Lena E. Bygballe, 2022)	X			X		
2	(WON J U N CHOI, 2022)			X		X		**33**	(Wesam Salah Alaloul M. L., 2019)			X	X		
3	(Ritu Ahuja, 2018)	X	X	X				**34**	(Frédéric Boschéa, 2013)			X		X	
4	(James Garbett, 2020)			X				**35**	(Robert Lopez, 2022)					X	
5	(Jad Chalhoub, 2021)			X				**36**	(Boateng, 2020)	X			X		
6	(Ya Hui Teo, 2022)			X		X		**37**	(Phillip Schönfelder, 2023)			X	X		
7	(Sanjay Bhattacharya, 2022)	X		X	X			**38**	(Shiyao Caia, 2019)			X	X		
8	(Ahmed.M. Eldeep, 2021)	X		X	X			**39**	(Jianpeng Cao, 2021)			X	X		
9	(Sejun Janga, 2018)	X		X		X		**40**	(Lang-Tao Wu, 2022)			X		X	
10	(Kangkang Duan, 2023)			X		X		**41**	(Müge Tetika, 2019)			X	X		
11	(Subhav Singh, 2020)	X		X	X			**42**	(Christoph Paul Schimanski, 2021)	X		X	X		
12	(Adrian Michalski E. G., 2022)	X		X	X			**43**	(Valerian Vanessa Tuhaise, 2023)			X	X		
13	(Mohammed Ali Berawia, 2019)			X	X			**44**	(Ming Shan Ng D. H., 2022)			X	X		
14	(Emad Bakhoum, 2023)			X	X			**45**	(Nathan Melenbrinka, 2020)			X	X		
15	(Ming Shan Ng D. H., 2022)			X	X			**46**	(David Carvajal-Arango, 2019)	X	X		X		
16	(Ming Shan, 2020)			X	X			**47**	(Wesam Salah Alaloul A. H., 2021)			X	X		
17	(Bock, 2015)			X	X			**48**	(Jos A.C. Bokhorst3', 2022)	X					X
18	(Samad M. E. Sepasgozar, 2023)			X	X			**49**	(Eder Martinez3', 2023)			X	X		
19	(Rita Lavikka, 2021)			X		X		**50**	(Rohin Titmarsh, 2020)	X	X	X			X
20	(Monique Rieger Rodrigues, 2021)	X		X	X			**51**	(Nedjwa ELAFRI, 2022)	X		X			
21	(Caleb Debrah, 2022)		X	X				**52**	(Biyanka Ekanayake, 2021)			X	X		
22	(Ayaz Khan 1, 2022)			X	X			**53**	(Antonio J. Sanchez-Garrido, 2023)			X	X		
23	(Rebecca Siegel a, 2019)	X	X					**54**	(Pascal Langlotza, 2021)	X		X			
24	(Mohammadsoroush Tafazzoli 1, 2020)	X	X					**55**	(A. Mayra, 2018)	X		X			X
25	(Agency, 2007)	X	X					**56**	(Elafei Najwaa', 2022)	X		X			X
26	(Rajeev Rathi a, 2022)	X	X					**57**	(Pellerin, 2022)	X		X			X
27	(Adrian Michalski E. G., 2022)	X		X	X			**58**	(Marina Marinelli, 2021)	X		X			X
28	(Kyuhyup Leea, 2018)			X	X			**59**	(Simon Schumachera, 2022)	X		X			X
29	(Vítor Pereira a, 2021)		X	X	X			**60**	(Larissa Stats. and Aparna Samaraweera, 2022)			X	X		
30	(Pedro Saieg, 2018)	X	X	X	X			**61**	(Qian Zhang, 2024)			X	X		
31	(Dhanasingh Sivalinga Vijayan, 2023)		X	X	X			**62**	(Anil Sawhney, 2020)			X	X		

4. Results and Debate

The Subject research consists of several aspects in which the framework shall be perfectly designed to serve the aim and objective of the study, Lean, Sustainability/Green, MEP System Construction, metrics, Environmental Value Stream Mapping E-VSM and the I4.0 technology, Each aspect is presented in the literature in macro or micro level, fragmented to include some aspects or formed to discuss different theoretical paradigm, the preliminary systematic Literature Review SLR shows that the whole research aspects not available in a single study theme, for this, Table 2 classify the related aspects according to the searching criteria for each article, then the analysis and synthesis shall be conducted to distil the conceptual relationship and how it can be extended within the context of the study in hand.

4.1 Publication Data Source

Figure 2 and Table 3 Illustrate the Number of Publication per database showing the proportional differences among them

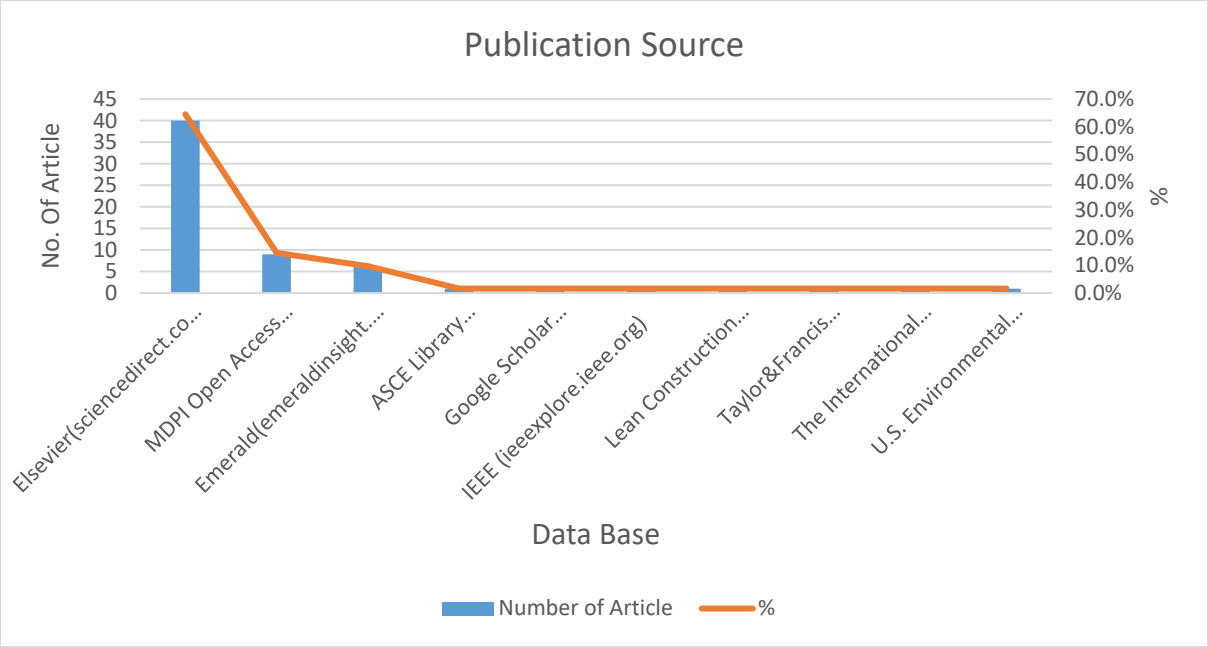

Figure 1. Publication Source

Table 3. Data Base Publication Source

Database	**No. of Articles**	**%**
Elsevier(sciencedirect.com)	40	64.5%
MDPI Open Access Journals (www.mdpi.com)	9	14.5%
Emerald(emeraldinsight.com)	6	9.7%
ASCE Library https://ascelibrary.org/	1	1.6%
Google Scholar (scholar.google.com)	1	1.6%
IEEE (ieeexplore.ieee.org)	1	1.6%
Lean Construction Journal (www.leanconstructionjournal.org)	1	1.6%
Taylor&Francis (T&F)(tandfonline.com)	1	1.6%
The International Association for Automation and Robotics in Construction (http://www.iaarc.org)	1	1.6%
U.S. Environmental Protection Agency (EPA) (http://www.epa.gov/lean)	1	1.6%

4.2 Article Number per Classified Category

As Illustrated In Section 3.2 and Figure 1 The assigned initial centric categories were Preliminary classified according to the Center aspect of the study from the viewpoint of the literature review at hand, in general, the results indicate that the topic of MEP Construction when it is evaluated to have the link to Lean, Green and technologies/I4.0 aspects gains less interest in the literature or still an emerging topic with 6% only of the total 62 articles as shown in Table 4, noting that with subject 6% (9 pieces of study) the whole research aspects not available in a single study theme, whereas the Technology/I4.0 and general construction centric studies gains more interest in the literature, this illustrating the existing gap in the literature where the study in-hand shall fill up relatively for the subject matter. These findings direct the literature review to evaluate the available literature via two paths, the first one is the Manufacturing-centric studies and the second is the General construction-centric studies in which both bathes shall contribute to form the base framework for the targeted MEP Construction-Centric frameworks in hand,

Table 4. Articles weight per Category

	Research Aspects	**%**
1	Lean,	18%
2	Green	8%
3	Technology/I4.0	37%
4	General Construction	25%
5	MEP Construction	6%
6	Manufacturing	5%

4.2.1 The Research Gap

This part illustrates the research gap from different authors' perspectives and backgrounds, generally, the SLR shows the assessment of the current construction sector as very slow in adapting to the current technological revolution in comparison to other industries such as manufacturing and communication, implicitly the question of " why the construction industry can't get a notable disruptive technological adaptation and integration to enhance the operation performance"? , and with several Management approaches especially Lean construction and green construction,
"There are currently many ambiguities and a lack of investigation into future directions and what construction workers should expect in the latter half of the 21st century" (Samad M. E. Sepasgozar, 2023). Another study investigating the combined model of Lean and green via BIM Technology in the construction sector AEC Argue that" even though there is an increasing volume of research in these fields, there is still little or no research that relates the three concepts or how to apply this synergy in the industry" (Pedro Saieg, 2018). Another Study Argues that "there is a lack of studies with a holistic view of I4.0 technologies and their application in Construction Industries. The existing literature often focuses on deciphering a narrow piece of I4.0 technology or tool" (Larissa Statsenko and Aparna Samaraweera, 2022). The discussion mainly projects the civil and architectural threads at first glance as the main element of the AEC sector which could be classified as " Static Systems" and The MEP System as a " Dynamic System" This classification takes the reference of the designed intention and ontology for each system at first consideration, of course the civil and architectural threads not a static system in absolute when it's relevant to the interaction with the surrounding environment such as seismic adapted towers however these towers designed to have a static state, unlike the MEP Systems which designed to transfer energy, Power etc…

4.3 Manufacture industry-centric Studies Analysis

The chosen articles in the field of manufacturing generally concentrate on business and engineering, along with management and accounting. Most of the papers' writers concentrated on manufacturing and how new technical solutions for sustainable and green production, especially from a management viewpoint, may be created by merging lean, green, and I4.0 principles. The Journal of Cleaner Production published the majority of the publications, the journal focuses on cutting waste and increasing the effectiveness of resources, such as energy, water, and human capital. The primary source, the International Journal of Production Research, suggests that the issue is primarily concerned with the integration of engineering and management. In engineering, manufacturing, production economics, sustainability, technology management, and logistics, lean, green, and I4.0 concepts have gained importance. The literature provides instances of connections between interest factors I4.0, lean, green, and operational performance; nevertheless, the analysis is top-level and excludes specific methods or instruments. Studies reveal that Industry 4.0 enhances lean productivity, Lean is the cornerstone of smart Industry 4.0 and increases lean efficiency (Jos A.C. Bokhorst3', 2022, Rohin Titmarsh, 2020, A. Mayra, 2018, Elafei Najwaa', 2022, Pellerin, 2022, Marina Marinelli, 2021, Simon Schumachera, 2022)

4.4 General Construction Industry-centric Studies Analysis

In general, the subject (36) studies included in this category, often focus on Technologies and process management. The majority of the authors focused on the Conceptual level of General construction and how combining concepts may result in new technological solutions to enhance operational performance, particularly from a management perspective. Some studies discuss the analysis and shed light on future directions for research and development of Lean and BIM initiatives, it is anticipated to promote thoughtful professional practice spurred by creative thinking for

the profitable use of BIM to provide Lean in the general construction context (Sanjay Bhattacharya, 2022), (Ahmed.M. Eldeep, 2021), (Subhav Singh, 2020), (Adrian Michalski E. G., 2022), Other studies assess the Individual technology tools such as Internet Of Things (IoT) platform's ability to enhance schedule performance and to suggest a new monitoring model, (Mohammed Ali Berawia, 2019), evaluate the effects of virtual reality in construction (Emad Bakhoum, 2023).

The study of (Ming Shan Ng D. H., 2022)Proposes a thorough synthesis outlining the factors that promote design for digital fabrication, the study develops a framework called "relational ontology" at a high-level conceptual level to show how various enablers/mechanisms (140 Nos.) are related to one another and presents a theoretical complex Process modelling for designing and managing construction automation, however, its lacks of clarity and simple practical steps. (Nathan Melenbrinka, 2020), concludes that much more work has to be done on general construction jobs before completely autonomous building can be achieved in unstructured contexts.

A similar study by (Ming Shan, 2020), (Valerian Vanessa Tuhaise, 2023) analyses the demands of the industry for digital fabrication/ industrialized construction and partially determines the information, instruments, and responsibilities connected to fabrication that are most important at various phases of the general design as well as the needs for platform-based management and propose a conceptual management framework for BIM-platform-based integration for digital fabrication design in construction projects, despite that the author toch a valid area of common digital design platform deficiency the outcome does not have validation and not considering the design reference requirement.

Propose a roadmap for developing some individual technologies for the construction sector by highlighting Emerging technologies and Identifying the challenges to implementing some technologies which could integrate with the construction processes, however, the proposals are still in the very early stage of theoretical expectation with no preliminary evidence of implementation, early experiment or case study in the general construction context.(Samad M. E. Sepasgozar, 2023), (Jianpeng Cao, 2021), (Wesam Salah Alaloul M. L., 2019), (Phillip Schönfelder, 2023), (Shiyao Caia, 2019), (Eder Martinez3', 2023)

The Studies conducted by (Pedro Saieg, 2018), (David Carvajal-Arango, 2019) and (Monique Rieger Rodrigues, 2021) suggest a complementary means among Lean, sustainability and BIM in the AEC sector by combining various technologies, techniques, and concepts, however, the study presents a general conceptual level of the literature review finding, no specific evidence of the relation, synergy or collaborative outcome of the initiatives in detail for specific construction activities.

Present a framework combining nine General construction technologies proposed for six operation scenarios, the proposed frameworks (Larissa Statsenko and Aparna Samaraweera, 2022), (Qian Zhang, 2024), explored the possible connections between sustainability and Construction C4.0, (Kyuhyup Leea, 2018), suggests an augmented reality-based job management system that takes advantage of smart gadgets. (Vítor Pereira a, 2021), (Christoph Paul Schimanski, 2021), Proposes a theory on how building information modelling (BIM) technology can or has already improved building efficiency, (Dhanasingh Sivalinga Vijayan, 2023) Suggests learning about the advantages of sustainable building through the use of eco-friendly materials and technology, (Lena E. Bygballe, 2022), (Biyanka Ekanayake, 2021) and (Wesam Salah Alaloul A. H., 2021) Discuss the Performance monitoring and measurement concerning Lean Construction LC and the last planner system LPS by identifying principal difficulties and offering recommendations for resolution, (Müge Tetik, 2019) proposes direct digital construction (DDC), a process management approach based on technology that aims to enhance building efficiency by reducing the need for individuals to interpret and reusing designs, however, the papers did not go beyond cited data from the literature and bring the technologies and the benefits together in one frame claiming the applicability by referencing other papers, so the question of how these technologies could contribute to the assigned target with clear practical examples or already implemented case studies is missing.

The handbook of (Anil Sawhney, 2020) Discusses the dispersed nature of professional activity, research, and education in the built environment field. By explaining Construction 4.0 in the context of its current condition, new trends and technologies, and the people and process challenges that surround the impending revolution, The general note highlights the challenge to implementing C4.0 Technologies might be a departure point for more detail and clear frameworks, (Antonio J. Sanchez-Garrido, 2023), (Ayaz Khan 1, 2022), (Adrian Michalski E. G., 2022), (Boateng, 2020), Conducted a Literature review in the field of modern construction methods, converge of lean and Building

information modelling BIM, in over all the papers does not place a specific solution instate it's a general study of construction 4.0 implementation benefits and challenges.

5. Conclusion

The integration of Lean, Green, and Industry 4.0 (I4.0) technologies into MEP systems represents a transformative approach to advancing sustainable practices in the construction industry. This study has systematically reviewed existing literature, identifying significant synergies, gaps, and opportunities in this evolving field. While substantial research exists on Lean, Green, and I4.0 principles individually, their collective application in MEP systems remains underexplored, emphasising the novelty and potential of this research direction, however, environmentally sustainable Lean MEP Construction within the technology revolution C4.0, is currently one of the strategic requirements for organizations, and it needs to be integrated with their conventional aims of productivity and revenue. Several aspects of the lean construction, green, and Industry 4.0 paradigms have been examined since implementing these practices in conjunction or sequentially has been examined as a possible strategy for reaching this kind of convergence, however, the bulk of the publications on this topic have been published during the previous five years, indicating that the discipline is still in its early phases of growth, This SLR provided a methodical analysis of the body of research on MEP green lean construction with the use of I4.0, or latest available technologies, to distil a clear aspect shall contribute to form the base framework for the targeted MEP Construction-Centric frameworks in hand. The Study has identified Six major Centric categories for each aspect, as shown in Fig 1. To be deployed, 1)lean, 2)Green/Sustainability, 3)Technologies/I4.0, 4)General Construction, 5)MEP construction and 6)Manufacturing, all operationalized, depending on their broad or small-scale nature, Where they were employed to identify communal characteristics across the literature, the systematic Literature Review SLR shows that the whole research aspects are not available in a single study theme, for this, Table 2 classifies the related aspects according to the search criteria for each article, and then the analysis and synthesis conducted to distil the conceptual relationship and how it can be extended within the context of the study in hand. In general, the results indicate that the topic of MEP Construction when it is evaluated to have the link to Lean, Green and technologies/I4.0 aspects gains less interest in the literature or is still an emerging topic with 6% only of the total 62 articles as shown in Table 4, noting that with subject 6% (9 pieces of study) the whole research aspects not available in a single study theme. Because of this, the Environmentally sustainable Lean MEP Construction within the technology revolution C4.0, idea was not entirely evident until recently, and there are still plenty of opportunities for more study to continue developing the streams that have already been identified. In conclusion, while the integration of Lean, Green, and I4.0 technologies in MEP systems is still in its infancy, it holds immense potential for revolutionising sustainable construction practices. Future research should aim to address identified gaps, prioritise practical applications, and foster innovation to make this vision a reality. By doing so, the construction industry can achieve enhanced efficiency, reduced environmental impact, and alignment with global sustainability goals.

References

A. Mayra, M. Weigelta, A. Kühla, S. Grimmb, A. Erlla, M. Potzela, J. Franke. "Lean 4.0 - A conceptual conjunction of lean management and Industry 4.0." *Science Direct* vol. 72, pp. 622-628, 2018.

Adrian Michalski, Eryk Głodziński, Klaus Böde. "Lean construction management techniques and BIM technology." *Procedia Computer Science* vol. 196, pp. 1036-1043, 2022.

Adrian Michalski, Eryk Głodzińskia, Klaus Böde. "Lean construction management techniques and BIM technology systematic literature review." *Procedia Computer Science* vol. 196, pp. 1036-1043, 2022.

Ahmed.M. Eldeep, Moataz.A.M. Farag, L.M. Abd El-hafez. "Using BIM as a lean management tool in construction processes – A case study." *Ain Shams Engineering Journal* vol. 13, no. 2, pp. 101556, 2021.

Anil Sawhney, Mike Riley, Javier Irizarry. "CONSTRUCTION 4.0 An Innovation Platform for the Built Environment." 1st ed., Routledge, 2020.

Antonio J. Sanchez-Garrido, Ignacio J. Navarro a, Jos´e García b, Víctor Yepes c. "A systematic literature review on modern methods of construction in building: An integrated approach using machine learning." *Journal of Building Engineering* vol. 63, pp. 106725, 2023.

Ayaz Khan, Rongrong Yu, Tingting Liu, Hong Guan and Erwin Oh. "Drivers Towards Adopting Modular Integrated Construction for Affordable Sustainable Housing: A Total Interpretive Structural Modelling (TISM) Method." *Buildings* vol. 12, no. 5, pp. 637, 2022.

Biyanka Ekanayake, Johnny Kwok-Wai Wong, Alireza Ahmadian Fard Fini, Peter Smith. "Computer vision-based interior construction progress monitoring: A literature review and future research directions." *Automation in Construction* vol. 127, pp. 103705, 2021.

Boateng, Temitope Seun Omotayo and Prince. "Systems thinking and CMM for continuous improvement in the construction industry." *International Journal of Productivity and Performance Management* vol. 69, no. 2, pp. 271-296, 2020.

Bock, Thomas. "The future of construction automation Technological disruption and the upcoming ubiquity of robotics." *Automation in Construction,* vol. 59, pp. 113-121, 2015.

Caleb Debrah, Albert P.C. Chan, Amos Darko. "Artifiial intelligence in green building." *Automation in Construction* vol. 12, no. 5, pp. 565-578, 2022.

Christoph Paul Schimanski, Nissim Lal Pradhan, Dmitry Chaltsev ,Gabriele Pasetti Monizza, Dominik. Matt. "Integrating BIM with Lean Construction approach: Functional requirements nd production management software." *Automation in Construction* vol. 124, pp. 103562, 2021.

David Carvajal-Arango, Sara Bahamon-Jaramillo, Paula Aristizabal-Monsalve,Alejandro Vasquez-Hernandez , Luis Fernando Botero Botero. "Relationships between lean and sustainable construction: Positive impacts of lean practices over sustainability during construction phase." *Journal of Cleaner Production* vol. 240, pp. 118205, 2019.

Dhanasingh Sivalinga Vijayan, Parthiban Devarajan 1 , Arvindan Sivasuriyan 1, Anna Stefa´nska 2,3,* ,. "A State of Review on Instigating Resources and Technological Sustainable Approaches in Green Construction." *Sustainability* vol. 15, no. 8, pp. 6751, 2023.

Eder Martinez3, Louis Pfisterb. "Benefits and limitations of using low-code development to support updates digitalization in the construction industry." *Automation in Construction* vol. 152, pp. 104108, 2023.

Elafei Najwaa', Rcse Beeteandb, Malsh Yassinec, Gabriela Fernandese, Majed Abdeene,. "Lean 4.0 tools and technologies to improve companies' maturity level : the COVID-19 context." *Science Direct* vol. 196, pp. 207-216, 2022.

Emad Bakhoum, , Ahmed A. Younis,, Hazem K. Aboulata, Andrew R. Bekhit. "Impact assessment of implementing virtual reality in the Egyptian construction industry." *Ain Shams Engineering Journal* vol. 14, no. 6, p. 102184, 2023.

Frédéric Boschéa, Adrien Guillemetb, Yelda Turkanc*, Carl T. Haasa, Ralph G. Haasa. "Tracking the built status of MEP works: Assessing the value of a Scan-vs-BIM system." *Journal of Computing in Civil Engineering* vol. 28, no. 4, pp. 0501-4004, 2013.

Jad Chalhoub, Steven K. Ayer and Kieren H. McCord. "Augmented Reality to Enable Users to Identify Deviations for Model Reconciliation." *Buildings* vol. 11, pp.77, 2021.

James Garbett, Thomas Hartley, David Heesom. "A multi-user collaborative BIM-AR system to support design and construction." *Automation in Construction* Vol.122,pp.0926-5805, 2020.

Jianpeng Cao, David Bucher, Daniel M. Hall, Jerker Lessing. "Cross-phase product confiurator for modular buildings using kit-of-parts." *Automation in Construction* vol. 123, pp. 103437, 2021.

Jos A.C. Bokhorst3', Wilfred Knolb,c, Jannes Slomp , Thomas Bortolotti3. "Assessing to what extent smart manufacturing builds on lean principles." *International Journal of Production Economics* vol. 253, pp. 108599, 2022.

Kangkang Duan, Christine Wun Ki Suen, Zhengbo Zou. "Robot morphology evolution for automated HVAC system inspections using updates graph heuristic search and reinforcement learning." *Automation in Construction* Vol.153,pp.104956, 2023.

Kyuhyup Leea, Soonwook Kwon, Taekyu Koa and Youngsuk Kimb. "A Study AR Based Smart Device for Work Management at Plant Construction Sites." vol. 89, pp. 86-98, 2018.

Lang-Tao Wu, Jia-Rui Lin , Shuo Leng , Jiu-Lin Li , Zhen-Zhong Hu,. "Rule-based information extraction for mechanical-electrical-plumbing-specifi semantic web." *Automation in Construction* vol. 135, pp. 104108, 2022.

Larissa Statsenko and Aparna Samaraweera, Javad Bakhshi, Nicholas Chileshe. "Construction 4.0 technologies and applications: a systematic literature review of trends and potential areas for development." *Construction Innovation* vol. 60, no. 2022, pp. 1-20, 2022.

Lena E. Bygballe, Sanne K. Sand-Holm 2, Ceyda Pakoglu 3 & Fredrik Svalestuen 4. "Challenges of Performance Measurement in Lean Construction and the Last Planner System: A Norwegian Case." *Lean Construction Journal* pp. 24-40, 2022.

Marina Marinelli, Abrar Ali Deshmukh,Mukund Janardhanan, Izabela Nielsen. "Lean manufacturing and Industry 4.0 combinative application Practices and perceived benefits." *Sciense Direct* vol. 54, no. 1, pp. 288-293, 2021.

Ming Shan Ng, Daniel Hall, Marc Schmailzl, Thomas Linner, Thomas Bock. "Identifying enablers and relational ontology networks in design for digital fabrication." *Automation in Construction* vol. 144, pp. 104592, 2022.

Ming Shan Ng, Daniel Hall, Marc Schmailzl, Thomas Linner, Thomas Bock. "Identifying enablers and relational ontology networks in design for digital fabrication." *Automation in Construction* vol. 144, pp, 104592, 2022.

Ming Shan, Marcella M. Bonanomi Daniel M. Hal and Jürgen Hackl. "Design for Digital Fabrication: an Industry needs Analysis of Collaboration Platforms and Integrated Management Processes." *The International Association for Automation and Robotics in Construction* vol. 37, pp. 318-325, 2020.

Mohammadsoroush Tafazzoli 1, *, Ehsan Mousavi 2 and Sharareh Kermanshachi. "Opportunities and Challenges of Green-Lean: An Integrated System for Sustainable Construction." *Sustainability* vol. 12, no. 11, pp. 4460, 2020.

Mohammed Ali Berawia, Adinugroho Sunardi and Mohammad Ichsan. "Chief-Screen 1.0 as the Internet of Things Monitoring & Controlling to Improve Project Schedule Performance Platform in Project." *Procedia Computer Science* vol. 161, pp. 731-738, 2019.

Monique Rieger Rodrigues, Søren Munch Lindhard. "Benefits and challenges to applying IPD experiences from a Norwegian mega-project." *Construction Innovation* vol. 23, no. 2, pp. 287-305, 2021.

Müge Tetik., Antti Peltokorpia, Olli Seppänena, Jan Holmström. "Direct digital construction: Technology-based operations management practice for continuous improvement of construction industry performance." *Automation in Construction* vol. 107, pp. 102910, 2019.

Nathan Melenbrinka, Justin Werfelb, Achim Mengesa. "On-site autonomous construction robots: Towards unsupervised building." *Automation in Construction* vol. 119, pp. 103312, 2020.

Nedjwa ELAFRI, Jordan Tappert, Bertrand ROSE, Maleh Yassine. "Lean 4.0: Synergies Between Lean Management Tools and Industry 4.0 Technologies." *ScienceDirect* vol. 55, no. 10, pp. 2060-2066, 2022.

Pascal Langlotza, Jan C. Auricha. "Causal and temporal relationships within the combination of Lean Production Systems and Industry 4.0." *ScienceDirect* vol. 54, pp. 1-15, 2021.

Pat Bartholomew, Kate V. Bates, Dave Bury. *Lean and Environment Toolkit.* Vols. 1st ed.,U.S. Environmental Protection Agency. 2007.

Pedro Saieg, Elisa Dominguez Sotelino, Daniel NascimentoRodrigo Goyannes Gusmao Caiado. "Interaction of Building information modelling, Lean and Sustainability on the Architectural, Engineering and Construction industry A systematic review." *Journal of Cleaner Production* vol. 174, pp. 788-806, 2018.

Phillip Schönfelder, Angelina Aziz, Benedikt Faltin, Markus König. "Automating the retrospective generation of As-is BIM models using machine learning." *Automation in Construction* vol. 135, pp. 104108, 2023.

Qian Zhang, Chang Liu , Wenhui Zhu and Shiqi Mei. "Demystifying the Inflencing Factors of Construction 4.0 Technology Implementation from a Sustainability Starting Point: Current Trends and Future Research Roadmap." *buildings* vol. 16, no. 1, pp. 123-140, 2024.

Qinglin Wu, Lijuan Chen, Peixin Shi, Weijun Wang and Sheng Xu. "Identifying Impact Factors of MEP Installation Productivity: An Empirical Study." *Buildings 2022,* vol. 12,pp. 565, 2022.

Rajeev Rathi a, Mahender Singh Kaswan a, *, Jose Arturo Garza-Reyes b, Jiju Antony c,. "Green Lean Six Sigma for improving manufacturing sustainability: Framework development and validation." *Journal of Cleaner Production* vol. 345, pp. 131130, 2022.

Rebecca Siegel a, Jiju Antony a, *, Jose Arturo Garza-Reyes b, Anass Cherrafi c,Bart Lameijer. "Integrated green lean approach and sustainability for SMEs From a literature review to a conceptual framework." *Journal of Cleaner Production* vol. 240, pp. 118205, 2019.

Rita Lavikka, Krishna Chauhan, Antti Peltokorpi and Olli Seppänen. "Value creation and capture in systemic innovation implementation case of mechanical, electrical and plumbing prefabrication in the Finnish construction sector." *Construction Innovation* vol. 21, no. 4, pp. 837-856, 2021.

Ritu Ahuja, Anil Sawhney, Mohammed Arif. "Developing organizational capabilities to deliver lean and green project outcomes using BIM." *Engineering, Construction and Architectural Management* Vol. 25, No.10, pp.1255-1276, 2018.

Robert Lopez, Heap-Yih Chong, and Conrad Pereira. "Obstacles Preventing the Off-Site Prefabrication of Timber and MEP Services: Qualitative Analyses from Builders and Suppliers in Australia." *Buildings* vol. 12, no. 7, pp. 1044, 2022.

Rohin Titmarsh, Fadi Assad, Robert Harrison. "Contributions of lean six sigma to sustainable manufacturing." *Procedia CIRP* vol. 90, pp. 589-593, 2020.

Rosin Frederic, Magnani Florian, Joblot Laurent, Pascal Forget Robert. "Lean 4.0: typology of scenarios and case studies to characterize Industry 4.0 autonomy model." *Science Direct* vol. 104, pp. 123-128, 2022.

Samad M. E. Sepasgozar, Ayaz Ahmad Khan, Kai Smith, Juan Garzon Romero, Xiaohan Shen, Sara Shirowzhan, Heng Li and Faham Tahmasebinia. "BIM and Digital Twin for Developing Convergence Technologies as Future of Digital Construction." *Buildings,* vol. 13, no. 2, p. 441, 2023.

Sanjay Bhattacharya, Ankur Mathur. "Synergising lean objectives through BIM to enhance productivity and performance." *International Journal of Productivity and Performance Management* Vol.1, pp.0401-1741, 2022.

Sejun Janga, Ghang Lee. "Process, productivity, and economic analyses of BIM –based multi-trade prefabrication — A case study." *Automation in Construction* vol. 89, no. 1, pp. 86-98, 2018.

Shiyao Caia, Zhiliang Maa, Miroslaw J. Skibniewskib,c,d, Song Baoe. "Construction automation and robotics for high-rise buildings over the past decades: A comprehensive review." *Advanced Engineering Informatics* vol. 42, pp. 100989, 2019.

Simon Schumachera, Roland Halla, Andreas Bildsteina, Thomas Bauernhansl. "Toolbox Lean 4.0 – Development and Implementation of a Database Approach for the Management of Digital Methods and Tools." *Science Direct* vol. 55, no. 10, pp. 2060-2066, 2022.

Subhav Singh, Kaushal Kumar. "A study of lean construction and visual management tools through cluster analysis." *Ain Shams Engineering Journal* vol. 12, no. 1, pp. 1153-1162, 2020.

Valerian Vanessa Tuhaise, Joseph Handibry Mbatu Tah, Fonbeyin Henry Abanda. "Technologies for digital twin applications in construction." *Automation in Construction* vol. 135, pp. 104108, 2023.

Vítor Pereira a, José Santos b,c, ⇑, Fernanda Leite d, Patrícia Escórcio b. "Using BIM to improve building energy efficiency – A scientometric and systematic review." *Energy & Buildings* vol. 250, pp. 111292, 2021.

Wesam Salah Alaloul, Abdul Hannan Qureshi. "Evolution of close-range detection and data acquisition technologies towards automation in construction progress monitoring." *Journal of Building Engineering* vol. 43, pp. 102877, 2021.

Wesam Salah Alaloul, M.S. Liew, Noor Amila Wan Abdullah Zawawi, Ickx Baldwin Kennedy. "Industrial Revolution 4.0 in the construction industry: Challenges and opportunities for stakeholders." *Ain Shams Engineering Journal* vol. 10, no. 3, pp. 345-356, 2019.

WONJUN CHOI, CHEEKYEONG KIM, SEOKJAE HEO, SEUNGUK NA. "The Modification of A∗ Pathfinding Algorithm for Building Mechanical, Electronic and Plumbing (MEP) Path." *IEEE Access* Vol.10,pp.65784-65800, 2022.

Ya Hui Teo, Jun Hong Yap, Hui An, Simon Ching Man Yu, Limao Zhang, Jie Chang. "Enhancing the MEP Coordination Process with BIM Technology and Management Strategies." *Sensors* Vol.22, pp. 4936, 2022.

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