COMBINING GREEN BUILDING AND LEAN CONSTRUCTION TO ACHIEVE MORE SUSTAINABLE DEVELOPMENT IN SOUTH AFRICA

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This paper explores the synergies that exist between lean construction and green building across all the development phases in a construction project to enhance sustainable development practices in South Africa. Using a systematic literature review, 68 articles were selected and coded. The findings indicate that: (i) lean construction and green building practices, principles, techniques, tools, and technologies can be simultaneously implemented across all phases of development, and offer multidimensional benefits in each; (ii) building information modelling plays a crucial role in assisting and facilitating lean construction and green building, mutually reinforcing each other throughout a development; (iii) prefabricated construction is becoming a popular way in which lean construction and green building are interacting and supporting each other; and (iv) the interaction between lean construction and green building can help to achieve more sustainable development in South Africa.

OPSOMMING

Die sinergieë tussen lenige konstruksie en omgewingsvriendelike (groen) boutegnieke wat bestaan tydens al die ontwikkelingsfases word ondersoek. Die doel is om sodoende die volhoubare ontwikkelingspraktyke in Suid-Afrika te verbeter. Deur 'n sistematiese literatuurstudie is 68 artikels gekies en kodeer. Die bevindings toon dat (i) lenige konstruksie en groen boupraktyke, -beginsels, -tegnieke, -instrumente en –tegnologieë gelyktydig op alle fases van ontwikkeling toegepas kan word en dat dit veelvuldige voordele vir elk inhou; (ii) die modellering van bou informasie speel 'n sleutel rol om lenige konstruksie en groen bou by te staan en te fasiliteer om sodoende mekaar te versterk; (iii) voorafvervaardigde konstruksie word 'n gewilde manier om lenige konstruksie en groen bou te vereenselwig en om mekaar te ondersteun; en (iv) die interaksie tussen lenige konstruksie en groen bou kan help om meer volhoubare ontwikkeling in Suid-Afrika te bereik.

1   INTRODUCTION

The construction industry represents 40 per cent of global energy consumption, 38 per cent of global greenhouse gas emissions, 12 per cent of global drinkable water use, and 40 per cent of solid waste streams [1-2]. The industry is also considered among the largest consumers of natural resources [1], [3-4]. The extraction, manufacturing, and transportation of raw materials have led to a significant reduction of resources and of biological diversity [4], [6]. High energy consumption creates acid rain, and continues to add to the negative effects of global warming [4].

The construction industry is a key and crucial player in driving economic growth in developing nations such as South Africa [6], [7]. The industry is characterised by high levels of waste, unreasonable use of water and electricity, the generation of large amounts of CO_2 emissions, and countless inefficiencies increasing waste throughout the development process [7], [8]. To counteract these inefficiencies in the design, construction, and operational stages of conventional construction, green building techniques and technologies are being implemented [9], [8]. Green building is when a construction project, in its design,

construction, and operational phases attempts to reduce or eliminate negative environmental and economic impacts, and aims to create significantly positive impacts on ecological and social environments [8-11]. Lean construction emphasises the need to reduce waste, optimise flows, and eliminate unproductive and unfruitful processes [12-13]. Green building and lean construction share a common goal, as they both strive for the efficient use of resources through the reduction of waste [13].

By reducing negative environmental, social, and economic impacts through green building, and by reducing waste in processes through lean construction, there is potential to enhance current sustainable development practices in South Africa [13]. Note that sustainable development in construction projects must be considered from a life cycle perspective, taking into account the planning, design, construction, operational, and disposal or demolition phases [14-18].

The primary objective of this research was to develop an explicit and thorough understanding of the synergies that exist between green building and lean construction throughout all stages of a construction development project. To achieve this, a systematic literature review was conducted, as it enabled the synthesis of valuable qualitative data to draw more accurate and concrete conclusions [19-20].

2   RESEARCH METHODOLOGY

2.1 Research design

The research adopted a qualitative research method in which the academic literature was analysed in a systematic and structured manner [19]. A systematic literature review is defined as a "systematic, explicit, and reproducible method for identifying, evaluating, and synthesizing the existing body of completed and recorded work produced by researchers, scholars, and practitioners" [21-23]. This approach allows for a high level of objectivity in both method and analysis, while simultaneously allowing the research to produce a comprehensive analysis of the academic literature in a selected field [24]. The review entailed collecting and obtaining accurate, clear, and relevant academic data that supported the study and assisted in addressing the objectives [20].

2.2 Data collection

The data collection protocol used carefully chosen qualitative means to collect the data and to ensure that the sample had depth, clarity, and quality. The correct research protocol was essential to ensure that the systematic review process was carefully planned prior to data collection and analysis. This minimised bias, improved consistency, and provided stricter research integrity and transparency [25], [60]. The data collection protocol for the systematic literature review was conducted through the steps outlined below [20], [24-27].

2.2.1   Step 1: Initial search

Using the primary objective of the research as a basis to establish keywords, eight phrases were created: 'Lean construction', 'Green building', 'Green construction', 'Lean principles in construction', 'Lean green construction', 'Sustainable construction supply chain'. 'Green principles in construction', 'Lean and green thinking'. 'Sustainable development' and 'sustainability' were excluded from the search terms, as 'sustainability' is intricately woven into the ideas of both 'green building' and 'lean construction'.

Table 1: Keywords and phrases to be placed in the databases

Keywords or phrases created	
Lean construction	Sustainable construction supply chain
Green building	Green principles in construction
Green construction	Lean and green thinking
Lean principles in construction	Lean green construction

Following the selection of the key phrases, all of them were placed sequentially into eight reliable and reputable multidisciplinary databases, as shown in Table 2 below.

Table 2: Multidisciplinary databases used in the collection of the data

Multidisciplinary databases	
Taylor and Francis	ProQuest
Web of Science	JSTOR
Scopus	EBSCOhost
Science Direct	Wiley Online Library

2.2.2 Step 2: Collect the data

Zotero software, which allows the storage and organisation of the qualitative data prior to coding in the computer-assisted (or aided) qualitative data analysis software (CAQDAS) NVivo, was used to collect and organise the research sample. Using Zotero, the downloaded articles were eliminated iteratively using strict inclusion and exclusion criteria, as depicted in Figure 1 below.
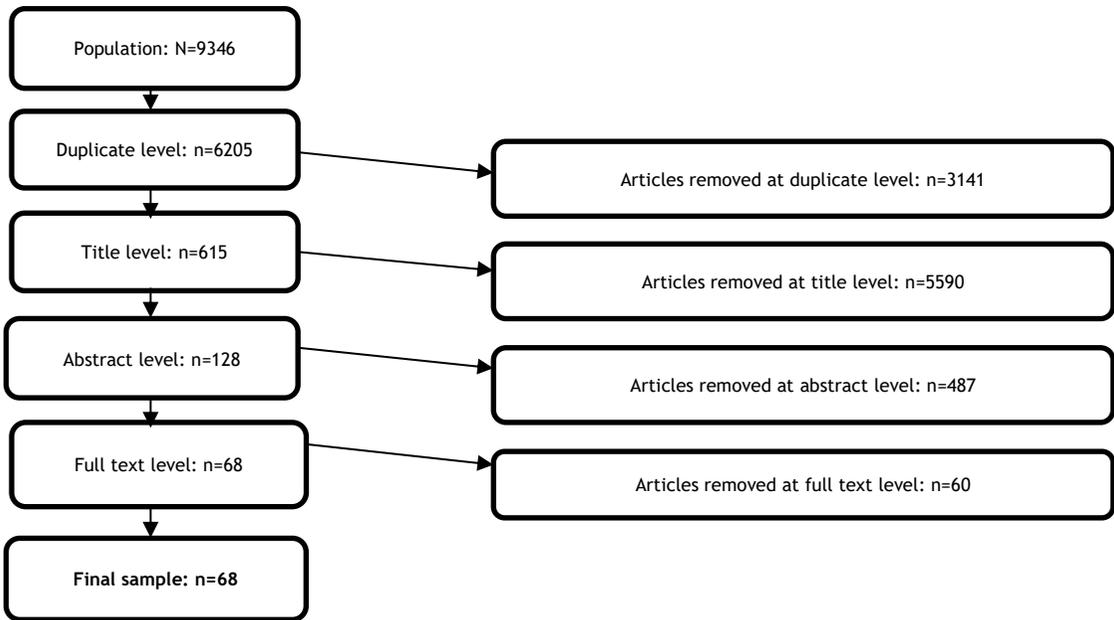
Population: N=9346

Duplicate level: n=6205 → Articles removed at duplicate level: n=3141

Title level: n=615 → Articles removed at title level: n=5590

Abstract level: n=128 → Articles removed at abstract level: n=487

Full text level: n=68 → Articles removed at full text level: n=60

Final sample: n=68

Figure 1: Process to eliminate articles

When entering the individual search terms into the databases, only articles that were written in English and that ranged from 2004 to 2019 were included in the search [19], [22]. Searching only for articles in English had the potential to increase language bias; however, the final report was written in English, and the exclusion of non-English studies had a negligible effect [22], [25]. A limited publication date allowed for the systematic review to be written using the most recent literature, thus making the findings more recent and relevant [19]. Non-academic sources (magazines, websites) were excluded in the filter settings. Journal articles, peer-reviewed articles, ongoing research articles, theses, books, book sections, and conference papers were included to avoid publication bias [22].

The initial search obtained a total of 9 346 articles, which served as the population for the research. The first elimination round removed all the duplicate articles. This reduced the sample to a total number of 6 205 articles. In the next step, articles were removed based on their title. The elimination by title was assessed primarily based on the contribution of the article to addressing the primary research objective, and reduced the number of total articles to 615 articles. This was conducted twice to ensure meticulousness and thoroughness. The next stage was to eliminate by abstract. Eliminating by abstract was evaluated based on whether the article could contribute to questions addressing the primary research objective. Elimination by abstract was conducted twice with the same criteria, to ensure academic depth and rigour. This step reduced the sample to 128 articles. The final stages of elimination were based on the full text, with stricter inclusion and exclusion criteria to refine the research further. Stricter criteria (Table 3) were used to ensure robustness and completeness in the data set and to ensure that the critical research question was answered and that the research objective was fulfilled [19].

The full-text articles were reviewed by an external moderator to ensure that those that were selected to write the final report were critically appraised and evaluated to ensure objectivity and avoid unnecessary

bias [25]. The external moderator also ensured that the remaining articles would achieve the goal of addressing the primary research objective. After all the elimination rounds had been completed, the final sample of 68 articles remained (see Figure 2 below). Figure 2 summarises the dates of publications that were included in the final sample, highlighting the relevance of the research and findings.

Table 3: Stricter criteria applied for elimination

| Stricter criteria applied when reading the full text		
Inclusion criteria (explicitly speaking to these points)		Exclusion criteria
Green construction	Lean principles in the design, construction, operational, and demolition stages of construction	Financing lean and green building
Lean construction	Green principles and practices in the design, construction, operational, and demolition stages of construction	Investments in green building
Green building	Holistic sustainable development (economic, environmental, and social)	Reviews on policies and law
Sustainability through lean and green practices in construction	Qualitative and quantitative research	Failure to obtain full-text article
Lean green supply chain management on construction sites	Articles that were specific to South Africa	The evolution of green building and lean construction
Incorporation of building information modelling to achieve more sustainable development	Lean and green applications in other countries	
Prefabrication of materials		
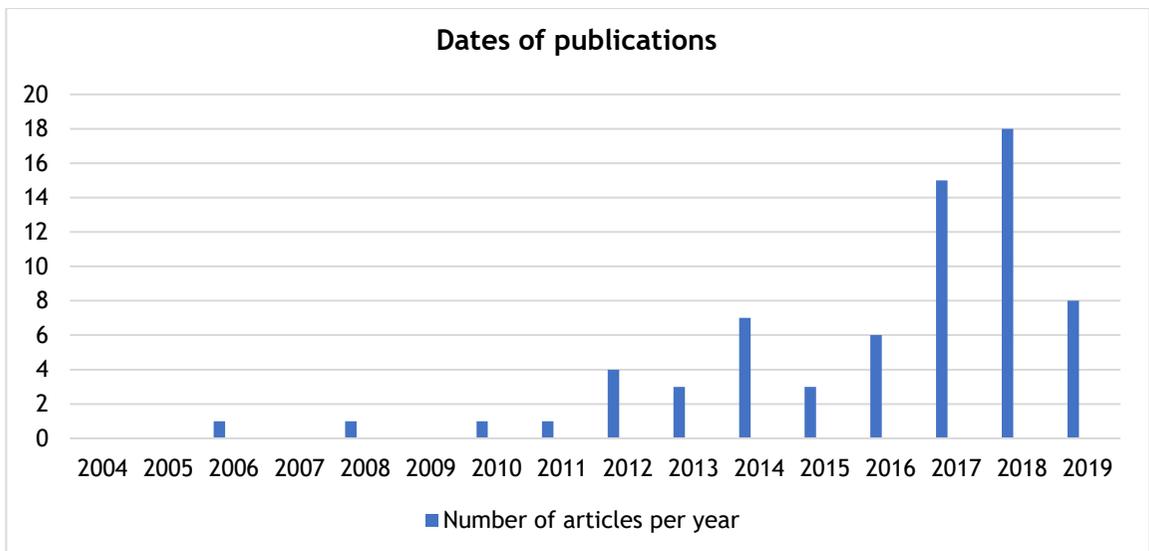
Figure 2: Dates of publications

2.2.3   Step 3: Analysis of the data and coding

The 68 articles were imported into NVivo CAQDAS software to be coded. NVivo is a qualitative data analysis software designed for very rich text-based information, which allows for intricate levels of analysis on large volumes of data [29]. The coding process was interpretive, and required summarising and condensing large amounts of data into a single word or phrase [30]. Each unique paragraph or line of text was assigned or coded into a unique node. The coding process allowed for the identification of patterns, where multiple authors expressed similar ideas, and where text shared commonality and was suitable to a certain node [30]. In many cases the coding filter adopted was 'descriptive coding', as the data was documented and categorised based on the variety of opinions of several authors [30]. Coding enabled the organisation and grouping of the qualitative data into nodes based on commonalities. The process of reading each full-text article from the final sample allowed for the nodes to become more refined and accurate. As the coding progressed, sub-codes were identified that were not originally considered [30].

2.3 Data analysis

The data analysis took the form of a textual narrative synthesis. This enables a data extraction format by which certain characteristics were extracted from the individual articles [19], [31]. This synthesis made use of segments of text from the articles by placing them into the designated node, which provided a foundation to write the extracted findings in the form of a narrative flowing systematic literature review [32]. Strict parameters were placed as early as possible in the analysis, such as pre-determined nodes, and only included articles that received intense objective scrutiny, ultimately minimising the subjectivity and bias. And each article was read individually, with key information then coded into the relevant nodes. Line by line coding was adopted to ensure objectivity and rigour [30].

In Table 4 below, the 'number of articles in nodes' column signifies the number of articles that are in each individual node, with 'lean and green in the preparation and design phases', 'lean and green in the construction phase' and 'lean construction' being the largest. The second column, 'extracted files from articles', signifies how many 'references' or paragraphs or sentences were placed into those nodes. It is noted that 'lean and green in the preparation and design phase', 'lean and green in the construction phase', and 'lean construction' were among the largest.

Table 4: Primary nodes in NVivo

Name of primary node	Number of articles in nodes	Extracted files from articles
Introduction	31	128
Green building	26	200
Lean construction	40	302
Lean and green in the preparation and design phases	45	283
Lean and green in the construction phase	46	304
Lean and green in the operational phase	16	64
Lean and green in the demolition phases	10	47

Figure 3 below provides a summary of the dates of publications that were included in the final sample, highlighting the relevance of the research and findings.
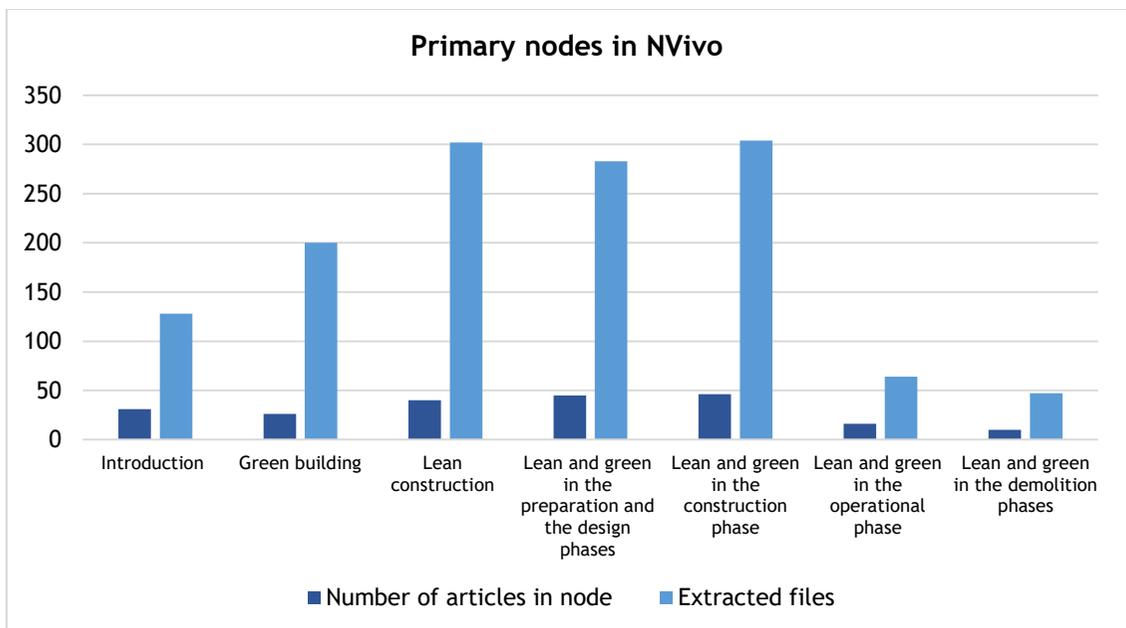

Figure 3: Primary nodes in graphical form

2.4 Synthesis

Subsequent to the preceding analysis, the systematic literature review was written in a narrative flowing style, journeying through each stage of a construction development. This started with 'lean and green in the preparation and design phases'; into 'lean and green in the construction phase'; into 'lean and green in the operational phase'; and last into 'lean and green in the demolition and disposal phases'.

3   DISCUSSION OF RESULTS

Concluding the synthesis, key findings and emergent findings were drawn from the review, providing an amalgamated discussion of the mutually reinforcing relationship that exists between lean construction and green building throughout every stage of a construction development. The literature highlighted that synergies do exist between both green building and lean construction, and that the two mutually reinforce each other, significantly enhancing sustainable development practices. The literature also highlighted how lean construction and green building interactions exist across the entire development life cycle. Key and unanticipated findings emerging from the systematic literature review are detailed below.

3.1   Preparation and design phases

First, the literature emphasised the importance of the preparation and design phase of a development, especially in minimising waste and establishing a strong foundation for the subsequent stages [33-37], [40]. In support of this, the implementation of lean construction and green building principles and practices must be done as early as possible in the project life cycle [37], [41]. The literature also emphasised that, to incorporate green building and lean construction effectively, project participants must adopt a more holistic development approach to align themselves with lean, green, and sustainability principles at every stage of the development, knowing that each stage affects the subsequent stage [14], [42], [39].

3.2   Design practices

Second, both lean and green building design practices support each other and mutually reinforce each other, as each will seek to optimise and address different aspects of design [37-39], [43-46]. Lean design provides insight into value creation and the reduction of waste across the life cycle of the development, while green building design seeks to address the environmental dimensions of design. These reinforcing principles enable the project team to consider the entire development, while simultaneously considering and adjusting to the social, economic, and environmental dimensions of the development [38-39], [46].

3.3   Mutual support (lean and green)

The support that green building and lean construction provide each other in the construction phase is important. Lean can assist in controlling and smoothing the number of activities in this phase to reduce waste, while green building principles can assist in integrating environmental considerations in reducing that waste further in an environmentally friendly manner [47-50]. And the two working together can significantly enhance the economic and social dimensions of the construction phase [38], [36], [48], [51].

3.4   Prefabricated construction

The use of prefabricated construction can realise both lean construction and green building benefits, outcomes, and goals [42], [47-48], [52]. Prefabrication is considered a green building technology, while it has also been viewed as the most effective method to realise lean construction [42], [47], [52]. Prefabrication enables lean construction through waste minimisation, improved construction productivity, improved efficiency, improved site safety, and improved quality [42], [52]. It simultaneously allows for green building to be realised, as it enables reduced energy consumption, reduced material waste, and reduced CO_2 emissions [16], [48], [50]. This synergistic relationship that prefabricated construction and components create allows the sustainability triple bottom line to be realised. The literature, however, emphasised the importance of considering the limitations of prefabricated construction [34], [52-53]. The need to improve the process of prefabricated construction was emphasised, as it has the potential to play a significant role in improving sustainable developments in the future [34], [52]. This implies that there is a need for research into how prefabricated construction has improved, and how it potentially contributes to realising sustainable development goals.

3.5   Operational phase

Simultaneously incorporating lean construction and green building practices into the operational phase of the building enables an improved workplace environment for occupants, enhanced safety, minimised operational waste, and improved building maintenance and performance [16], [18], [47], [54-56].

3.6   Demolition and deconstruction phase

When lean construction and green building thinking are applied to the demolition and deconstruction phase, it is significantly dependent on the considerations from the previous phases [33]. The use of prefabricated construction and of recyclable and reusable materials had been considered at the design stage, through design for demolition or deconstruction (DfD) principles [33-34], [37]. The incorporation of

lean construction significantly minimises waste, while green building principles are applied through the incorporation of recyclable and reusable materials. The literature also highlighted that there is a significantly small amount of research being completed in this phase, compared with the other phases of the development. Opportunities for future research for the application of lean and green in this phase are thus opened up.

3.7 Building information modelling (BIM)

Building information modelling (BIM) models and analysis are important in facilitating lean construction and green building in every phase of the development. BIM plays a significant role in allowing the two concepts to work together seamlessly across all stages of the development. BIM can be used in the design, construction, operational, and demolition phases, allowing an improved visualisation throughout each stage. The literature constantly highlighted how BIM is fundamentally woven into the fabric of both lean construction and green building practices [37], [46], [48], [54-55].

3.8 The lean supply chain

Incorporating green building principles into the lean supply chain, particularly when selecting suppliers and choosing materials, is key [57]. Interestingly, the review revealed that there is a great need for research into the application of lean construction and green building and their integration together at a supply chain level, particularly with supplier selection and materials.

3.9 Emergent themes

A number of unanticipated results emerged. The first was that the application of lean construction in practice may have a significantly negative effect on the health of workers through the number of motions and tasks required [16]. However, it was found in a later study that lean, from a social perspective, can improve health and safety when applied in practice owing to the improved work environment that is created and the accurate processes used in handling materials [18]. Thus there is a need for long-term analysis of the health implications for workers.

The next unexpected finding was that, initially, the just-in-time (JIT) delivery system of prefabricated components was deemed not to be an environmentally friendly delivery system, as JIT requires multiple trips to the site, which increase CO_2 emissions when transporting [44]. However, more recent literature shows that JIT can greatly enhance the sustainability of lean supply practices [50]. Assessing the sustainability of JIT provides a potential gap for research to be conducted.

It was interesting to discover that the integration of BIM and geographical information improves utility and asset management, and optimises concrete truck mixer routes to minimise emissions and improve delivery time, while also improving site feasibility analysis [58-59], [37].

The incorporation of information technology (IT) and the Internet of Things (IoT) into making prefabricated construction leaner and more efficient was found to be emerging in the literature [42]. It is inevitable that the research into the application of Fourth Industrial Revolution principles in assisting lean construction and green building will increase exponentially.

4   CONCLUSION

In conclusion, this paper, using a systematic literature review, structurally and methodically explored the synergies between green building and lean construction, and how those synergies can enhance sustainable development practices. The paper provided strong evidence, using 68 articles from the academic literature, to support the notion that synergies do exist between the two concepts; and how these two concepts, in unison, can enhance sustainable development practices, despite the need for a practical implementation in a South African context.

This paper can greatly assist industry, both theoretically and practically. From a theoretical perspective, a systematic review of the academic literature has been provided that clearly highlighted the synergies between lean construction and green building, and how that helps to achieve more sustainable development. The paper also has practical implications, as it has provided suggestions to practitioners who are looking to implement certain tools, techniques, and practices from both green building and lean construction, and how their interaction can improve the way they carry out construction activities. It also provides practitioners with information on how green building and lean construction interact in each unique phase of a development, providing the practitioner with a more holistic view when developing.

4.1 Limitations

A potential limitation of the paper is that the level of applicability of the two working concepts together in the South African context would need to be addressed further, as the local environment has its own practices, limitations, and barriers. This may affect the validity of the findings; however, many articles included studies that were done in developing nations, which may improve the applicability to the South African context.

4.2 Further research opportunities

Multiple research opportunities have been recommended in the findings section, but there are several that are directly related to the paper.

The first opportunity for further research would be to apply the above results in a practical local context. This could be done using a case study approach in a South African context, where both green building techniques and technologies, together with lean practices and principles, are being implemented and used in a development, from the preparation and design phase, through into the construction, operational, and demolition phases. The sustainability can then be measured against a matrix. The sustainability findings could then be compared against a development that has not implemented green building or lean construction practices. This comparison of the two would allow the theory to be put into practice, and would allow baseline measurements of how lean and green can improve sustainable development practices.
Second, research could be conducted on the implementation of green building and lean construction practices in each of the individual stages of the lifecycle of a building, particularly in a South African context.

Other opportunities for research include: investigating the interaction of green building and lean construction in the deconstruction and demolition phase of the development; conducting both qualitative and quantitative research into the supply chain interactions of green building and lean construction; and analysing the sustainability of the lean construction concept of JIT.

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