Villanueva, M., Ma, H., Tjell, J., Ramos, G., and Turmo, J. (2022). An Implementation of Lean Approach to Achieve Working Time Efficiency in Precast Factory. Lean Construction Journal 2022 pp 41-61 (Submitted 28Dec21; Accepted 16Nov22) www.leanconstructionjournal.org

A Theoretical Framework Based on a Quantitative Assessment of the Interaction Between Commonly Used Lean Construction Tools and Techniques Through the Project Management Knowledge Areas

Manuel Villanueva[1], Haiying Ma[2], Janni Tjell[3], Gonzalo Ramos[4], José Turmo[5]

Abstract

Research Question: How do Lean Construction (LC) tools and techniques interact quantitatively with the project management knowledge areas (PMKAs) in construction projects?

Purpose: To provide a theoretical framework to quantify the relationship between LC tools and techniques (LCTTs) with the PMKAs of the PMBOK construction extension guide, since prior investigations were mostly qualitative.

Research Method: The authors performed an exhaustive literature review of 61 international papers from 2010 to 2020, followed by a quantitative analysis.

Findings: The quantitative analysis revealed that some LCTTs improve several of the main PMKAs.

Limitations: The authors have selected papers related to building sector projects with a range of 10 years (from 2010 to 2020). Also, some of the most relevant LCTTs have been selected (6) and their main benefits have been analyzed.

Implications: The use of the proposed framework will enable construction project managers and other professionals to understand the benefits of the interaction between LCTTs through the different PMKAs. From a practical perspective, this study could allow them to select the most suitable LCTTs for each PMKA depending on each particular need.

Keywords: Lean Construction, tools, techniques, PMBOK, Lean Project Management, Agile, Predictive, Hybrid, quantitative analysis.

Paper type: Full paper.

[1] Project Manager at Cognita, Associated Professor at Universitat Ramon Llull and PhD in Construction Engineering at Universitat Politècnica de Catalunya, Barcelona, Spain manuel.villanueva@salle.url.edu

[2] Tongji University, Shanghai, China, mahaiying@tongji.edu.cn corresponding author.

[3] PhD at Chalmers University of Technology, Gothenburg, Sweden. janni.tjell@ncc.se.

[4] Full Professor, Universitat Politècnica de Catalunya – BarcelonaTECH, Barcelona, Spain. gonzalo.ramos@upc.edu

[5] Professor, Universitat Politècnica de Catalunya – BarcelonaTECH, Barcelona, Spain. jose.turmo@upc.edu

Introduction

The construction sector has a big impact on our society but compared with other industries, the productivity is much lower historically (Shaping the Future of Construction,2016). The high uncertainty in construction projects could be mentioned as one of the main reasons but there are plenty of reasons that make this industry full of complexities and therefore hard to manage (Porras Díaz et al., 2014; Shaping the Future of Construction, 2016).

Over the years, this situation has forced the industry to discover new systems which could help in having more control and efficiency in construction projects. As a result, during the '90s, two main approaches appeared. The first one was a guide created by the Project Management Institute (PMI) called Project Management Book of Knowledge (PMBOK) (Project Management Institute, 2017). Their aim was to unify some of the Project Management (PM) lessons learned and they have been updating this guide since then. In the second one, Professor Koskela (1992) also challenged the Construction Industry to explore and adopt principles of "Lean Production" in Construction and introduced the theory of "transformation, flow and value" named "Lean Construction" (LC).

Although the situation has been improved with the appearance of some new PM and LC tools and techniques (LCTTs), there is still work needed to enhance the effectiveness of construction PM. Thus, this study provides a theoretical framework for identifying how some LCTTs could improve PM performance. To achieve this, a literature review of 61 international papers, from 2010 to 2020, have been quantitatively analyzed. As a result, Project Managers and Lean practitioners may be able to quantitatively understand the relationship between LC and PM and the benefits beyond this partnership. That will allow them to select the best LCTTs considering the PMKAs that they want to improve.

The following section of this document provides the context for the theoretical framework proposed as well as an explanation of the PM approaches and the lean techniques for construction projects. Then, the results of the research methodology are presented and finally, in the last section, the discussion and conclusions of the results are explained.

Project management approaches in construction

Although construction projects have traditionally been managed with a predictive approach based on a well-planned scope, an important number of them normally fail in cost overruns and delays (Blanco et al., 2020) which is the main part of the renowned iron triangle in PM (Davis, 2014; M. G, 2018; Nara et al., 2015; Bannerman, 2008). With this scenario, Ballard and Howell (2003) introduced a new approach called Lean Project Management (LPM) in 2003 and explained how LPM differs from traditional project management not only in the goals it pursues but also in the structure of its phases and the relationship between stakeholders.

Due to construction projects being complex and developing in a non-linear environment, several authors, like professor Koskela, have recommended including

some agile approaches in construction to better handle the high uncertainty (Alarcón et al., 2009; Owen et al., 2004; Stracusser, 2015).

Nowadays, projects are even more dynamic and changeable than before in most cases (Project Management Institute, 2018). This need has motivated the industry to merge predictive and agile methodologies through a hybrid approach (Lalmi et al., 2021).

According to PMI's report pulse of the profession (Project Management Institute, 2018), 47% of the projects still use predictive approaches meanwhile 23% use agile and 23% hybrid, and just 7% other approaches.

PMBOK® Guide (PMBOK Agile, 2017; Project Management Institute, 2017 and 2021) also recommends that each team choose the approach to use, taking into account both requirements and technical degree uncertainty as it is shown in Figure 1.

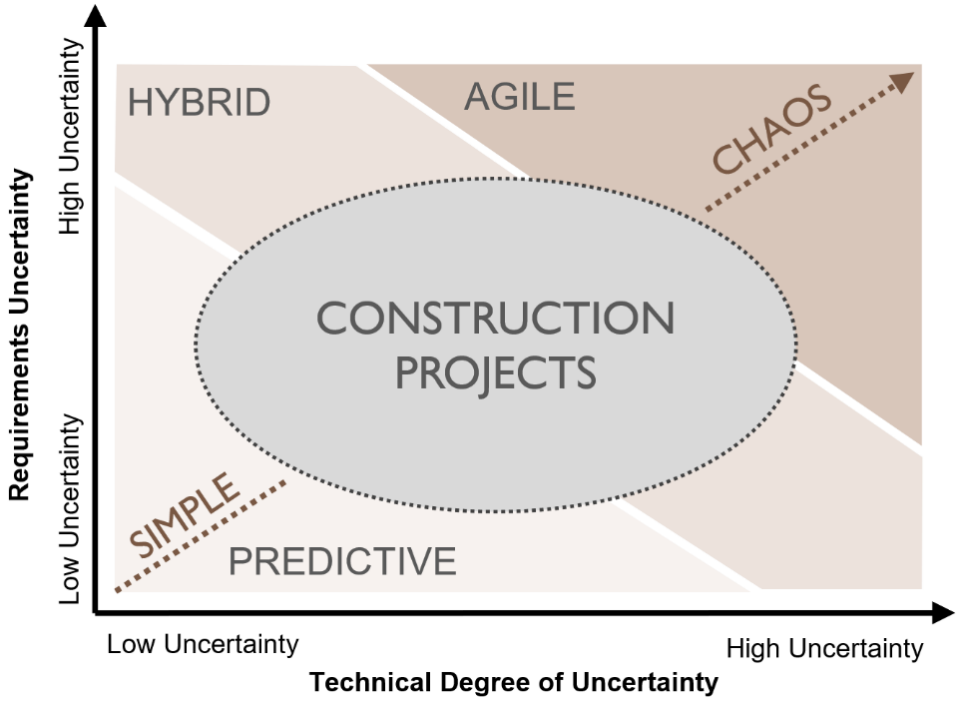

Figure 1. Uncertainty and Complexity Model inspired by Stacey Complexity model adapted from the PMBOK Agile Guide (PMBOK Agile, 2017).

The review of the three aforementioned approaches provides the basis to understand which of them is the most appropriate to apply in the theoretical framework that has been developed in this research.

Lean Construction tools & techniques

According to the research by Cho et al.(2011), McGraw Hill Construction (2013), Mossman (2015), and Sarhan et al. (2017), Lean Thinking was established to improve the construction industry through the following actions:

- Enhance customer and stakeholder satisfaction.

- Improve quality and safety meanwhile, risks are reduced.
- Increase productivity by reducing wastage (time and cost).
- Improve supplier relationships with better inventory control.
- Better collaboration between stakeholders thanks to full commitment, respect and accountability.
- Kaizen thinking by continuously improving implementations.
- Reduce variation thanks to higher reliability.

The construction extension to the PMBOK® Guide ((Project Management Institute, 2016)) also explains that it is important in terms of sustainability to adopt Lean Construction principles that allow for reducing waste of materials, time and effort.

A detailed description of the LCTTs and the criteria to select them has been developed in the following methodology section.

Research methodology

A literature review has been developed in this research to create the theoretical framework proposal. To achieve it, 7 different scientific and reliable databases were examined, in particular: Scopus, Elsevier-Science Direct, Taylor & Francis, Springer Link, ProQuest, ASCE, and Emerald Insight. Furthermore, some websites specialized in LC were consulted as the International Group of Lean Construction (IGLC.net) and the Lean Construction Institute (leanconstruction.org). Finally, some project management content was checked at the Project Management Institute website (pmi.org).

Due to the number of LCTTs, the authors have selected the six LCTTs with the highest impact in the field of Building Construction (BC) based on the literature reviewed in this document (McGraw Hill Construction,2013) and based on publications by experts (Ballard, Tommelein, Koskela and Howell, 2018): Last Planner System® (LPS®), Integrated Project Delivery (IPD), Value Stream Mapping (VSM), Target Value Design (TVD), Just-In-Time(JIT), and 5S.

To choose the correct articles, the following keywords were searched: ‘Lean Construction’, ‘pmbok’, ‘Last Planner System’, ‘integrated project delivery’, ‘value stream mapping’, ‘target value design’, ‘just in time’, ‘5s’, ‘Lean tools’, ‘Lean techniques’, ‘traditional project management’, ‘lean project management’ and ‘agile project management’. To make the findings more significant, several combinations of the above-mentioned keywords have been used.

Considering the keywords and databases mentioned above, the first result of 857 papers was obtained and then, each of these documents was examined in depth. All those papers which rely on civil works, especially for bridges and roads were intentionally removed. As a result, a total of 63 international papers from 2000 to 2020 were obtained as Figure 2 shows.

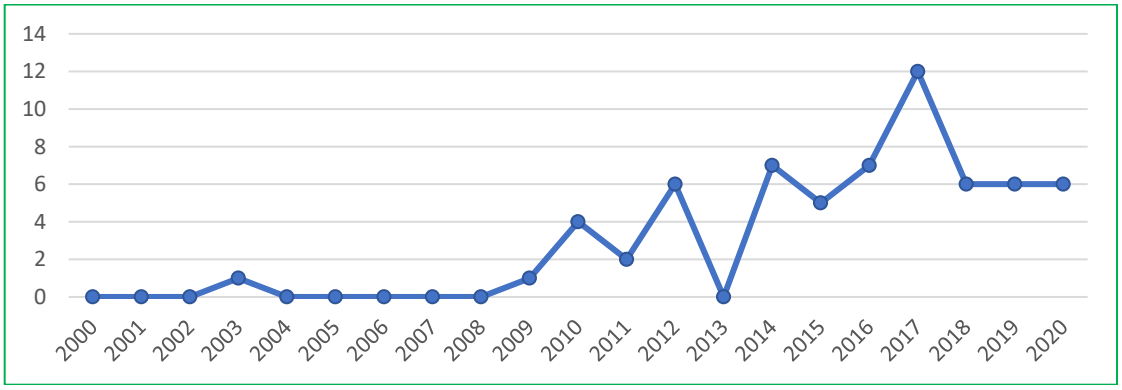

Figure 2. Classification of references used in this paper according to the year of publication.

Finally, we have considered the most recent publications (61) from 2010 to 2020 to carry out the theoretical framework proposed. To link the selected LCTTs to a PM standard, the PMBOK® Guide (Project Management Institute, 2017 and 2021) has been used as it is the reference guide for Project Managers worldwide. Besides complying with construction industry interests, the construction extension of that guide has been used (Project Management Institute, 2016), as is shown in Table 1. The PMKAs described in Table 1 start on number four because the first three chapters of the guide are generic PM content.

Table 1. PMBOK® Knowledge areas including the Construction Extension.

KNOWLEDGE AREAS	GUIDE
4. Project INTEGRATION Management	Project Management Body of Knowledge (PMBOK® Guide 6th and 7th edition)
5. Project SCOPE Management	
6. Project SCHEDULE Management	
7. Project COST Management	
8. Project QUALITY Management	
9. Project RESOURCE Management	
10. Project COMMUNICATION Management	
11. Project RISK Management	
12. Project PROCUREMENT Management	
13. Project STAKEHOLDER Management	
14. Project HEALTH, SAFETY, SECURITY and ENVIRONMENTAL Management	Construction Extension to the PMBOK® Guide
15. Project FINANCIAL Management	

The Integration between the six LCTTs most applied in Building Construction and the PMBOK® KA already described in Table 1, has been used to develop the theoretical framework proposed in this research.

Results

Sixty-one publications have been reviewed. Table 2 illustrates the references of those publications and shows the relationship between the LCTTs selected and the PMKAs of the PMBOK® Construction Guide. Indeed, this table allows an understanding of how many papers (experts) consider that each LCTT provides an improvement through the different PMKAs.

Table 2. Relationship between the LCTTs with the PMKAs of the PMBOK® Construction Guide.

PMBOK CONSTRUCTION GUIDE [30]·	LPS	IPD	VSM	TVD	JIT	5S
4. INTEGRATION	9	13	2	6	0	0
5. SCOPE	21	11	9	9	4	5
6. SCHEDULE	29	11	4	7	6	6
7. COST	18	18	5	10	6	6
8. QUALITY	18	10	7	7	6	9
9. RESOURCE	23	10	3	7	5	5
10. COMMUNICATION	21	11	2	4	1	4
11. RISK	15	16	2	5	3	2
12. PROCUREMENT	9	16	3	7	2	0
13. STAKEHOLDER	15	19	2	7	2	3
14. HS & ENVIRONMENTAL	15	4	4	2	2	9
15. FINANCIAL	3	7	0	2	2	0
TOTAL	**196**	**146**	**43**	**73**	**39**	**53**

With the purpose of designing the theoretical framework, we have compared quantitatively the impact of LCTTs with the PMKAs of the PMBOK® based on the bibliographic references previously described.

To properly assess Table 2, a summary chart was created in Table 3. In addition, the percentage of publications per KAs has been calculated for each LC tool to enrich the analysis and a color scale that represents the grade of each LCTTs implication has been included. Red tones mean a low level and green tones refer to a higher level of benefit, considering the number of papers that mention those advantages.

Table 3 reveals, the interaction of each LCTT with the PMKAs. This table could be read both from the left to the right and from the top to the bottom.

Horizontally, it displays the percentage of mentions per PMKAs. With a total of 550 results, the ratios are the following: 5.5% integration, 10.7% scope, 11.5% schedule, 11.5% cost, 10.4% quality, 10.4% resource, 7.8% communication, 7.8% risk, 6.7% procurement, 8.7% stakeholder, 6.5% HS and 2.5% financial.

Vertically, it shows the impact of each LCTTs through the PMKAs. For example, LPS has the following results at the PMKAs: 4.59% integration, 10.71% scope, 14.80% schedule, 9.18% cost, 9.18% quality, 11.73% resource, 10.71% communication, 7.65% risk, 4.59% procurement, 7.65% stakeholder, 7.65% HS and 1.53% financial.

Table 3. Percentage of each PMKAs for each LC tool and Technique.

PMBOK CONSTRUCTION GUIDE [30]·	LSP	IPD	VSM	TVD	JIT	5S	TOTAL OF PMKAS
4. INTEGRATION	4.59%	8.90%	4.65%	8.22%	0.00%	0.00%	**5.5%**
5. SCOPE	10.71%	7.53%	20.93%	12.33%	10.26%	9.43%	**10.7%**
6. SCHEDULE	14.80%	7.53%	9.30%	9.59%	15.38%	11.32%	**11.5%**
7. COST	9.18%	12.33%	11.63%	13.70%	15.38%	11.32%	**11.5%**
8. QUALITY	9.18%	6.85%	16.28%	9.59%	15.38%	16.98%	**10.4%**
9. RESOURCE	11.73%	6.85%	6.98%	9.59%	12.82%	16.98%	**10.4%**
10. COMMUNICATION	10.71%	7.53%	4.65%	5.48%	2.56%	7.55%	**7.8%**
11. RISK	7.65%	10.96%	4.65%	6.85%	7.69%	3.77%	**7.8%**
12. PROCUREMENT	4.59%	10.96%	6.98%	9.59%	5.13%	0.00%	**6.7%**
13. STAKEHOLDER	7.65%	13.01%	4.65%	9.59%	5.13%	5.66%	**8.7%**
14. HS & ENVIRONMENT	7.65%	2.74%	9.30%	2.74%	5.13%	16.98%	**6.5%**
15. FINANCIAL	1.53%	4.79%	0.00%	2.74%	5.13%	0.00%	**2.5%**
TOTAL	**196 (36%)**	**146 (27%)**	**43 (8%)**	**73 (13%)**	**39 (7%)**	**53 (10%)**	**550 (100%)**

Theoretical framework design

The proposed theoretical framework consists of two approaches. The first one explains for each LCTT studied what are the benefits for each PMKAs and it is described with detail in Figure 5 in the appendix. It illustrates one graph for each tool in which the percentage of benefits of using the tools is shown in the external circle and the PMKAs appear in the internal ring. The PMKA can be identified by its number, defined previously in Table 1. Thanks to that, Project Managers and Lean practitioners can see quantitatively that by using for example IPD, the cost management could improve by 12%.

The second part of the theoretical framework is explained in Figure 3. It represents in a histogram the percentage of the benefit of each LCTT for each PMKAS. Thanks to that, Project Managers and Lean practitioners can see quantitatively what LCTTs use, depending on the need of the project. For example, regarding the results of

this study, the most suitable LCTTs for schedule management would be LPS®, but improving integration management would be recommended for IPD. The use of one LCTT with another is not exclusive, so the benefit could increase if the same LCTTs are used at the same time.

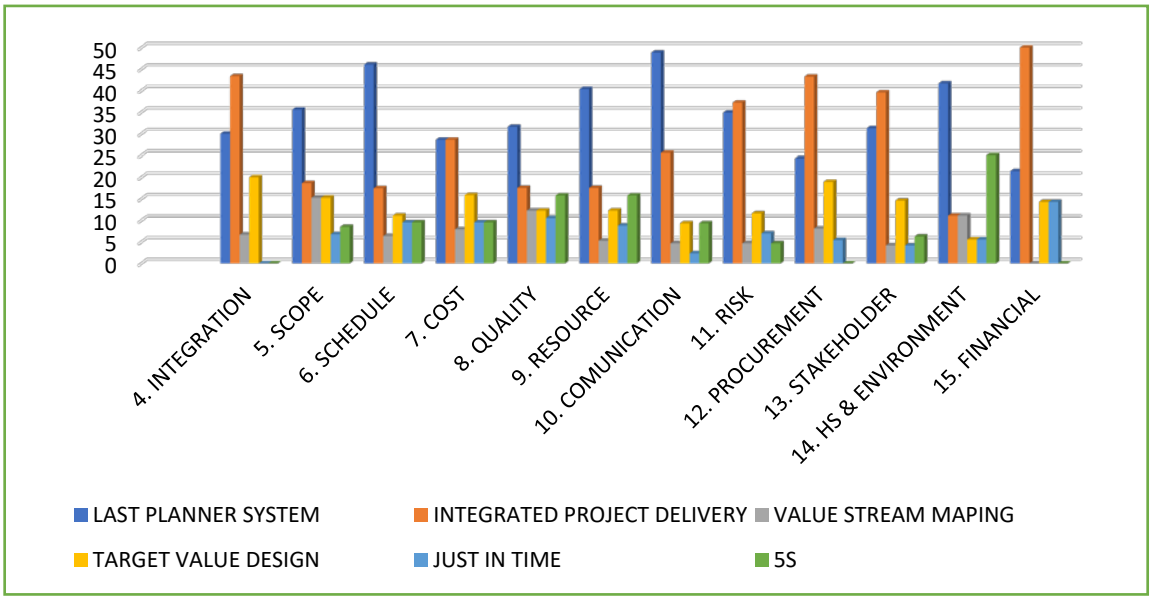

Figure 3. PMKAs percentage of improvement for each LC tool based on table

Discussion

To our knowledge, the present study analyzes for the first time the interaction between the LCTTs and the PMKAs.

Table 3 shows how LPS is the LC tool with the highest impact on the PMKAs, with (36%), followed by IPD (27%) and TVD (13%). On the opposite side, 5S (10%), VSM (8%) and JIT (7%) are the tools with less impact on the 12 PMKAs.

In addition, Table 3 also shows that the use of the LCTTs analysis improves most of the PM KAs. Owing to the importance of this finding, a deeper analysis has been developed for each LC tool considering that 100% are the sum of all PMKAs, each LC tool has been analyzed with special attention to those PMKAs with the highest impact:

Last Planner System®

LPS was developed by Glenn Ballard and Greg Howell (Ballard, 2000) with the intention of having greater production control through a collaborative review of schedule management. This tool is focused on improving workflow by identifying restrictions (Ballard, 1999).

Table 3 shows that 36% of the total papers mention that LPS® improve some PMKAS. The results of this study demonstrates that the highest impact (14.8%) of LPS® corresponds to schedule management which was the main purpose when LPS® was created (Ballard, 2000). Although LPS® is applied during schedule management and its main benefits come from it, it has an important impact on the rest of the management

areas. For instance, 10% of the benefits of implementing LPS® are associated with the scope because LPS® clarifies what should be done and the Work Breakdown Structure (WBS) is reviewed every week. Twelve percent also affect resources because, during the pull planning session, the means needs are clarified by asking the owner of each task about how much time, cost, and resources are necessary. As a result of these meetings face to face, the main project stakeholders work closer to improving communication management (11%). Also, the schedule is an essential tool for communicating with other stakeholders.

Integrated Project Delivery

IPD is a project delivery approach based on the collaboration between the main stakeholders aimed to improve efficiency through the project life cycle, especially during the phases of design and construction (AIA., 2007).

Considering the results of this research (Table 3), the PMKAs with the highest benefit from using IPD is the stakeholder management (13%), thanks to the collaboration previously mentioned throughout the phases of the project. The traditional construction projects are usually carried out by a huge quantity of different people, for a short period and with opposite interests. As a result, a lot of problems appear during the project provoking delays, risks, and cost overruns, among others (Porras Díaz et al., 2014).

This collaboration is formalized normally by an IPD contract that involves the main parts (developer, architect/engineers, and main contractor). The main purpose of this contract is to centralize the objectives of the project by sharing risks and benefits. That is why, 12% of the benefits belong to cost management, 11% to risk management, and 11% to procurement management.

Value Stream Mapping

VSM is a graphical technique that allows us to identify the activities that do not add value to the process and then carry out some solutions to eliminate them.

Some papers (Alvarez-Perez et al., 2018; Gunduz et al., 2019; Karningsih et al., 2018; Lledó et al., 2018; Parfenova et al., 2020; Sarhan et al., 2017; Seth, 2017) have studied the contribution of VSM in construction projects and have achieved a reduction of waste and cost in the process flow.

Our results show that the main primacy of using VSM belongs to scope management (21%). This tool helps Lean practitioners to focus on the activities that really add value to the customer, and remove those which are just waste. This action provokes to have an optimized scope and therefore reduces cost and increases quality. In fact, 12% of the total improvements rely on cost management and 16% on quality management.

Target Value Design

TVD is a management technique that helps maximize value during the project life cycle (Zimina et al.,2012). Traditional construction projects normally develop the design first and then estimate the cost of that project (Alvarez-Perez et al., 2018;

Ballard , 2012). In TVD the first consideration is the cost that the client foresees and then the design is adapted to that restriction (De Melo et al.,2016; Do et al., 2014).

In our research, around 14% of the advantages of implementing TVD belong to cost management because the TVD helps to control cost overruns and 12% corresponds to scope management since the WBS is more realistic.

Just in time

JIT is a tool commonly used in construction for eliminating waste by receiving goods only when it is necessary and just the quantity required for that moment (Malyavin, 2014; Purushothaman et al., 2020). For those reasons, there is usually less scope to be developed and then the cost and schedule are reduced. In addition that provokes an optimization of the resources with better quality results. Figure 5 in appendix shows that those PMKAs represent around 70% of the improvement.

5S

The construction industry makes frequent use of this tool on-site in cases where it helps to set in order and clean the work area (Prashant et al., 2017; Randhawa et al., 2017). Although 5S is part of the quality management and represents in our research the 17% of the improvements, there are other PMKAs such as Resource and Health and safety Management which signify 34% of the benefits of using this tool. The site is a safer place If most of the materials and means are ordered and the site is cleaned regularly.

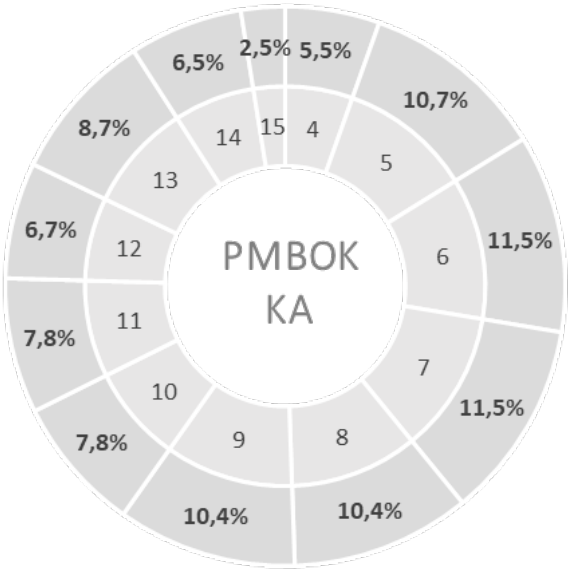

Figure 4. PMBOK® KA percentage based on Table 3.

Finally, it is worth mentioning the most affected KA of the PMBOK by the LC tools. Figure 4 shows a small part of Table 3 which is worth detailing. Figure 4 also represents through percentages, the relationship between the LC tools and techniques analyzed through the PM KAs of the PMBOK® Construction Guide. According to priority, the cost and the schedule management (11.5% each) are the PMKA with the highest improvement

of all the LC tools and techniques studied. Then, the scope management (10.7%), the quality management (10.4%), the stakeholder management (10.4%), the resource management (7.8%), the risk management (7.8%), the procurement management (6.7%), the Health & Safety management (6.5%), the integration management (5.5%) and finally the financial management (2.5%).

The main finding is that the LCTTs studied in this research provide the highest benefits in terms of cost, schedule, scope and quality management (44,1%). These essentially take the main part in the famous Iron Triangle, traditionally considered the core of PM (Bannerman, 2008; Davis, 2014; M. G et al., 2018; Nara et al., 2015).

Conclusion

In the introduction to this study, the relationship between LC and PM to deal with the complexity of construction projects has been described. Prior to this study, the benefits of each have mostly been analyzed from a qualitative point of view.

To our knowledge, this is the first research that presents a theoretical framework for identifying how much some LCTTs could quantitatively enhance PM performance. From our perspective it is relevant to understand the interaction between LCTTs and the PMKAs in construction projects for the following reasons:

1. There is a lack of quantitative analysis about the benefit of using LCTTs because previously, most of the studies have been qualitative. Based on this, we could understand the real impact based on data and not only in a conceptual way.
2. There is a lack of understanding about how the LCTTs affect the PMKAs, which in turn affect how construction projects could be managed.

Based on this investigation and the analysis developed, was found that the six LCTTs studied, improve a certain level of the twelve construction PM areas. Additionally, it has been demonstrated that the individual Lean tools and techniques were not only affecting specific PM areas but several. For instance, although LPS® is applied during schedule management and its main benefits come from this, it has an important positive impact on the rest of the PMKAs, especially in the scope, resource and communication management. As a result, this study shows that several PM areas could also be improved at the same time, even when only onelean tool is implemented.

Regarding the PM areas, the most impacted ones by the LC tools studied, are cost, schedule, scope and quality (44.1%) which traditionally have been called the iron triangle which is essentially the core of PM and key to project success.

For all of that, this research reinforces the idea already mentioned by the PMBOK® Agile guide (PMBOK Agile, 2017) and some experts (Alarcón et al., 20; Lalmi et al., 2021; Owen et al., 2004; Stracusser, 2015) who have recently recommended the use of a hybrid approach based on a predictive PM approach with some Lean techniques, for better construction project management performance. Using this, project managers and lean practitioners could be able to select which lean tools they could use depending on the PMKAs that they would like to improve.

Further investigation into the benefits of some other LC tools and techniques that could potentially make a positive impact on PM performance will help to deepen, and improve the way that construction projects are currently managed.

Acknowledgements

This work has been developed by an Industrial PhD grant subsidized by the Catalonia Government (Generalitat de Catalunya). This allowed Universitat Politècnica de Catalunya, UPC, BarcelonaTech, and the company Cognita to share know-how.

The authors are indebted to the Spanish Ministry of Economy and Competitiveness for the funding provided through the research project BIA2017-86811-C2-1-R directed by Jose Turmo. This project is funded with FEDER funds. The authors are also indebted to the Secretaria d'Universitats i Recerca de la Generalitat de Catalunya for the funding provided through Agaur (2017 SGR 1481)

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest concerning the research, authorship, and/or publication of this article.

References

Adamu I, Howell G. Applying Last Planner® in the Nigerian Construction Industry. In: 20th Annual Conference of the International Group for Lean Construction. 2012. p. 1–25. (1)

Ajay R, Sridhar MB. Incorporation of 5S methodology in construction practices. Int J Chem Sci. 2016;14:127–34. (2)

Alarcón L, Pellicer E. A new management focus: Lean Construction. Public Work Mag. 2009;3496(0034–8619):45–52. (3)

Alarcón L, Pellicer E. A new management focus: Lean construction. Rev Obras Publicas. 2009;156(3496). (4)

Álvarez MÁ, Bucero A, Pampliega CJ. Integrated project delivery, an alternative to the usual form of construction work in Spain. Build Manag [Internet]. 2017;1(3):30–6. Available from: http://polired.upm.es/index.php/building_management/ (5)

Álvarez, MA; Pellicer, E; Soler M. Target Value Design. A different way of approaching the constructive process in Spain. J Mod Proj Manag. 2018;5(3):1–17. (6)

Aslesen S, Tommelein ID. What "makes" the last planner? a typology of behavioral patterns of last planners. In: IGLC 2016 - 24th Annual Conference of the International Group for Lean Construction. 2016. p. 43–52. (7)

Ballard G, Howell G. An update on Last Planner. In: 11th Annual Conference of the International Group for Lean Construction. 2003. p. 1–10. (8)

Ballard G, Tommelein I, Koskela L, Howell G. Lean construction tools and techniques. In: Design and Construction. 2018. p. 251–79. (9)

Ballard G, Tommelein I. Current Process Benchmark for the Last Planner System. Lean Constr J. 2016;13(1):57–89. (10)

Ballard G, Vaagen H, Kay W, Stevens B, Pereira M. Extending the last planner system® to the entire project. Lean Constr J. 2020;42–77. (11)

Ballard G. Can pull techniques be used in design management? In: Conference on Concurrent Engineering in Construction. 1999. p. 18. (12)
Ballard G. Target Value Design. An Overview. In: Design Organisation and Management. 2012. p. 11–22. (13)
Ballard G. The Last Planner System of production control. University of Birmingham; 2000. (14)
Bannerman PL. Defining project success: a multilevel framework. In: PMI Research Conference: Defining the Future of Project Management. 2008. p. 1–21. (15)
Blanco JL, Mischke J, Ribeirinho MJ, Rockhill D, Sjödin E, Strube G, et al. The next normal in construction. How disruption is reshaping the world's largest ecosystem. McKinsey & Company. 2020. (16)
Bravo A, Mendoza J, Ramirez H. Application of Integrated Project Delivery and Virtual Design and Construction to reduce the impact of incompatibilities in the design stage in residential buildings. In: LACCEI international Multi-conference for Engineering, Education and Technology Jamaica. 2019. p. 24–6. (17)
Brioso X. Integrating ISO 21500 Guidance on Project Management, Lean Construction and PMBOK. Procedia Eng. 2015;123:76–84. (18)
Caballero O S, Zambrano O B, Ponce B E. Current status of the application of the lean construction methodology in the management of construction projects in Colombia. Ingeniare. 2018;2(25):27–60. (19)
Cho S, Ballard G. Last Planner and Integrated Project Delivery. Lean Constr J. 2011;(2):67–78. (20)
Daniel EI, Pasquire C, Ameh OJ. The magic of the Last Planner® system for Nigerian construction. In: 22nd Annual Conference of the International Group for Lean Construction: Understanding and Improving Project Based Production, IGLC 2014. 2014. p. 605–16. (21)
Daniel EI, Pasquire C, Dickens G, Ballard G. The relationship between the Last Planner® System and collaborative planning practice in UK construction. Eng Constr Archit Manag. 2017;24(3):407–25. (22)
Davis K. Different stakeholder groups and their perceptions of project success. Int J Proj Manag. 2014;32(2):189–201. (23)
Do D, Chen C, Ballard G, Tommelein ID. Target value design as a method for controlling project cost overruns. 22nd Annu Conf Int Gr Lean Constr Underst Improv Proj Based Prod IGLC 2014. 2014;1(510):171–81. (24)
Glenn GAB, Howell. Lean project management. Build Res Inf. 2003;31(2):119–33. (25)
Gunduz M, Naser A. Value Stream Mapping as a Lean Tool for Construction Projects. Int J Struct Civ Eng Res. 2019;8(1):69–74. (26)
Hall DM, Scott WR. Early Stages in the Institutionalization of Integrated Project Delivery. Proj Manag J. 2019;50(2):128–43. (27)
Hamzeh F, Ballard G, Tommelein ID. Rethinking Lookahead Planning to Optimize Construction Workflow. Lean Constr J. 2012;15–34. (28)
Hiwale A, Wagh A, Waghmare V, Khairnar D, Champanerkar S, Mane P. Effectiveness of 5s Implementation in Lean Construction (Commercial Building Construction Project). Int J Res Appl Sci Eng Technol. 2018;6(6):62–5. (29)
Hunt RJ, Gonzalez VA. Innovation in the New Zealand construction industry – Diffusion of the Last Planner System. In: 26th Annual Conference of the International Group for Lean Construction: Evolving Lean Construction Towards Mature Production Management Across Cultures and Frontiers. 2018. p. 422–31. (30)

Integrated Project Delivery: A Guide. Vol. 1. The American Institute of Architects (AIA); 2007. 62 p. (31)

Kahvandi Z, Saghatforoush E, ZareRavasan A, LapaViana M. A Review and Classification of Integrated Project Delivery (IPD) Implementation Enablers. J Constr Dev Ctries. 2020;44(1):1–20. (32)

Kalsaas BT, Grindheim I, Læknes N. Integrated Planning vs. Last Planner System. In: 22nd Annual Conference of the International Group for Lean Construction: Understanding and Improving Project Based Production,. 2014. p. 639–50. (33)

Kalsaas BT. The Last Planner System Style of Planning: Its Basis in Learning Theory. J Eng Proj Prod Manag. 2012;2(2):88–100. (34)

Karningsih PD, Anggrahini D, Karim MB, Adhitama R. Improving project efficiency using Lean Construction. In: Proceeding - ICAMIMIA 2017: International Conference on Advanced Mechatronics, Intelligent Manufacture, and Industrial Automation. IEEE; 2018. p. 334–6. (35)

Khanh HD, Kim SY. A survey on production planning system in construction projects based on Last Planner System. KSCE J Civ Eng. 2016;20(1):1–11. (36)

Korb S, Haronian E, Sacks R, Judez P, Shaked O. Overcoming "but we're different": An IPD implementation in the middle east. In: IGLC 2016 - 24th Annual Conference of the International Group for Lean Construction. 2016. p. 3–12. (37)

Koskela L, Stratton R, Koskenvesa A. Last planner and critical chain in construction management: Comparative analysis. In: Challenging Lean Construction Thinking: What Do We Think and What Do We Know? - 18th Annual Conference of the International Group for Lean Construction, IGLC 18. 2010. p. 538–47. (38)

Koskela L. Application of the new production philosophy to construction. Vol. 72. 1992. (39)

Lalmi A, Fernandes G, Souad SB. A conceptual hybrid project management model for construction. Procedia Comput Sci. 2021;181(2019):921–30. (40)

Lledó MJ, Cerveró F. Last Planner System is already a reality. Towards Lean transformation cf construction companies. In: CONTART. 2018. p. 154–63. (41)

M. G, A.M.A. Y. Analysis of project success factors in construction industry. Technol Econ Dev Econ. 2018; (42)

Malyavin I. Supply Chain Management: Just-In-time logistic in construction. Auckland University of Technology. School of Engineering. 2014. (43)

McGraw Hill Construction. Lean Construction. Leveraging Collaboration and Advanced Practices to Increase Project Efficiency. The Routledge Companion to Lean Management. 2013. (44)

Mejía-Plata C, Guevara-Ramirez JS, Moncaleano-Novoa DF, Londoño-Acevedo MC, Rojas-Quintero JS, Ponz-Tienda JL. A route map for implementing last planner® system in Bogotá, Colombia. In: IGLC 2016 - 24th Annual Conference of the International Group for Lean Construction [Internet]. 2016. p. 83–92. Available from: https://www.iglc.net (45)

Melo S, Do D, Tillmann P, Ballard G, Granja AD. Target value design in the public sector: evidence from a hospital project in San Francisco, CA. Archit Eng Des Manag. 2016;12(2):125–37. (46)

Millones Mateus M. Management methodology based on lean construction and PMBOK; To improve productivity in construction projects. Véritas. 2020;21(2):39–44. (47)

Miron LIG, Kaushik A, Koskela L. Target value design: The challenge of value generation. In: 23rd Annual Conference of the International Group for Lean Construction: Global Knowledge - Global Solutions. 2015. p. 12. (48)

Mossman A. Last Planner. 5 + 1 crucial & collaborative conversations for predictable design & construction delivery. The Change Business Ltd. 2015;1–36. (49)
Mossman A. What is Integrated Lean Project Delivery? The Change Business Ltd. 2008;1–2. (50)
Mossman, Alan; Ballard, Glenn; Pasquire C. Lean Project Delivery - Innovation in Integrated Design & Delivery. Des Manag Handb. 2010;165–90. (51)
Moylan WA, Arafah N. Integrated Project Delivery: Complicated Collaboration or Improbable Panacea. PM World J. 2017;VI(VII):28–35. (52)
Munje AS, Patil DS. Comparative Study of Last Planner System Over Traditional Construction Processes. Curr Trends Technol Sci. 2014;3(4):308–11. (53)
Nanda U, Rybkowski ZK, Pati S, Nejati A. A value analysis of lean processes in target value design and integrated project delivery: Stakeholder perception. Heal Environ Res Des J. 2017;10(3):99–115. (54)
Nara É, Besteiro C, Pinto JDS, Novaski O. Success factors in Project Management. Bus Manag Dyn. 2015;4(9):19–34. (55)
Nguyen P, Akhavian R. Synergistic Effect of Integrated Project Delivery, Lean Construction, and Building Information Modeling on Project Performance Measures: A Quantitative and Qualitative Analysis. Adv Civ Eng. 2019;2019(1267048):9. (56)
Oladiran OJ. An investigation into the usage of lean construction techniques in Nigeria. J Constr Proj Manag Innov. 2017;7(1):1712–25. (57)
Owen RL, Koskela L. Agile Construction Project Management. Struct Surv. 2004;22(2):22–33. (58)
Parfenova EN, Avilova ZN, Ganzha AN. Lean construction – an effective management system in the construction industry. In: IOP Conference Series: Materials Science and Engineering. IOP Publishing Ltd; 2020. (59)
Pheng LS, Shang G. The application of the Just-in-Time philosophy in the Chinese construction industry. J Constr Dev Ctries. 2011;16(1):91–111. (60)
PMBOK Agile. Practice Guide. Project Management Institute, Incl.; 2017. (61)
Porras Díaz H, Sánchez Rivera OG, Galvis Guerra JA. Lean Construction philosophy for the management of construction projects: a current review. Adv Eng Res. 2014 Dec 1;11(1):32. (62)
Prashant S. Kuklare DMNH. Implementation Of Lean Construction Theory: By Using 5'S Methodology As Tool - Case Study. Glob J Eng Sci Res Manag. 2017;4(3):95–100. (63)
Priven V, Sacks R. Effects of the Last Planner System on Social Networks among Construction Trade Crews. Am Soc Civ Eng. 2015;141(6):1–11. (64)
Project Management Institute. A Guide to the Project Management Body Of Knowledge (PMBOK Guide). 6th ed. Project Management Institute, Incl.; 2017. 370 p. (65)
Project Management Institute. A Guide to the Project Management Body of Knowledge (PMBOK Guide). 7th ed. 2021. 370 p. (66)
Project Management Institute. Construction Extension to the PMBOK® Guide. Project Management Institute, Incl.; 2016. (67)
Project Management Institute. Success in disruptive times: expanding the value delivery landscape to address the high cost of low performance. Pulse of the Profession. 2018. (68)
Purushothaman M babu, Seadon J, Moore D. Waste reduction using lean tools in a multicultural environment. J Clean Prod. 2020;265:121681. (69)

Randhawa JS, Ahuja IS. 5S – a quality improvement tool for sustainable performance: literature review and directions. Int J Qual Reliab Manag. 2017;34(3):334–61. (70)

Ryan M, Murphy C, Casey J. Case study in the Application of the Last Planner® System. In: 27th Annual Conference of the International Group for Lean Construction, IGLC 2019. 2019. p. 215–26. (71)

Sarhan JG, Xia B, Fawzia S, Karim A. Lean construction Implementation in the Saudi Arabian Construction Industry. Constr Econ Build. 2017;17(1):46–69. (72)

Seth D, Seth N, Dhariwal P. Application of value stream mapping (VSM) for lean and cycle time reduction in complex production environments: a case study. Prod Plan Control. 2017;28(5):398–419. (73)

Shaping the Future of Construction. A Breakthrough in Mindset and Technology. World Economic Forum (WEF). 2016. (74)

Shingate, N.P and Dr. Hedaoo M. A Review on Last Planner System. Int J Eng Technol Sci Res. 2017;4(12):1176–82. (75)

Skinnarland S. Norwegian Project Managers and foremen's experiences of collaborative planning. In: IGLC 2012 - 20th Conference of the International Group for Lean Construction. 2012. p. 10. (76)

Stracusser G. Agile Project Management Concepts Applied to Construction and Other Non-IT Fields. In: PMI Global Congress. Project Management Institute.; 2015. p. 1–9. (77)

Sundararajan S, Madhavi TC. Last planner implementation in building projects. In: Proceedings of the 26th Annual Conference of the International Group for Lean Construction: Evolving Lean Construction Towards Mature Production Management Across Cultures and Frontiers. 2018. p. 840–7. (78)

Viana ML, Hadikusumo BHW, Mohammad MZ, Kahvandi Z. Integrated Project Delivery (IPD): An Updated Review and Analysis Case Study. J Eng Proj Prod Manag. 2020;10(2):147–61. (79)

Viana, Daniela; Mota, Bruno; Formoso, Carlos; Echeveste, Marcia; Peixoto, Marjana; Rodrigues C. A Survey on the Last Planner System: Impacts and difficulties for implementation in brazilian companies. In: 18th Annual Conference of the International Group for Lean ConstructionAt: Haifa, Israel. 2010. p. 12. (80)

Wu X, Yuan H, Wang G, Li S, Wu G. Impacts of lean construction on safety systems: A system dynamics approach. Int J Environ Res Public Health. 2019;16(2). (81)

Yee LS. An Empirical Review of Integrated Project Delivery (IPD) System. Int J Innov Manag Technol. 2017;8(1):1–8. (82)

Zimina D, Ballard G, Pasquire C. Target value design: using collaboration and a lean approach to reduce construction cost. Constr Manag Econ. 2012;30(5):383–98. (83)

Appendix

Extension of Table 2. Relationship between the LCTTs with the PMKAs of the PMBOK® Construction Guide.

PMBOK CONSTRUCTION GUIDE (30)·	LPS		IPD		VSM		TVD		JIT		5S	
4. INTEGRATION	(11) (30) (36) (45) (49) (71) (72) (75) (78)	9	(5) (17) (18) (27) (32) (49) (50) (52) (54) (56) (62) (79) (82)	13	(26) (73)	2	(6) (13) (28) (32) (46) (83)	6		0		0
5. SCOPE	(1) (8) (10) (11) (21) (22) (28) (30) (33) (34) (36) (36) (38) (41) (49) (51) (64) (71) (72) (75) (76) (78)	21	(5) (20) (27) (32) (50) (51) (52) (54) (62) (79) (82)	11	(6) (17) (26) (41) (59) (69) (72) (72) (73)	9	(6) (13) (17) (24) (46) (48) (54) (72) (83)	9	(43) (57) (60) (69)	4	(2) (63) (69) (70) (72)	5
6. SCHEDULE	(1) (3) (5) (6) (7) (10) (11) (17) (19) (20) (21) (22) (28) (30) (33) (36) (38) (41) (47) (49)	29	(5) (27) (28) (32) (37) (50) (52) (54) (56) (79) (82)	11	(26) (35) (69) (73)	4	(6) (13) (24) (46) (48) (54) (83)	7	(43) (57) (60) (69) (72) (81)	6	(2) (29) (63) (69) (70) (72)	6

	(51) (53) (57) (64) (71) (72) (75) (76) (78)											
7. COST	(1) (7) (10) (11) (19) (21) (22) (28) (30) (36) (38) (49) (53) (71) (72) (75) (76) (81)	18	(5) (6) (20) (27) (30) (32) (37) (41) (49) (50) (51) (52) (54) (56) (62) (79) (82)	18	(26) (35) (41) (69) (73)	5	(6) (13) (17) (24) (46) (48) (51) (54) (72) (83)	10	(5) (43) (59) (60) (69) (81)	6	(2) (29) (59) (63) (69) (72)	6
8. QUALITY	(7) (10) (11) (19) (20) (21) (22) (28) (36) (38) (49) (51) (53) (64) (71) (75) (76) (78)	18	(5) (27) (32) (37) (50) (52) (54) (62) (79) (82)	10	(6) (26) (41) (59) (69) (72) (73)	7	(6) (13) (24) (46) (48) (54) (83)	7	(43) (57) (59) (60) (69) (81)	6	(2) (17) (29) (41) (57) (63) (69) (70) (72)	9
9. RESOURCE	(1) (7) (10) (11) (19) (20) (21) (22) (25) (28) (30) (33) (36) (38)	23	(3) (5) (27) (32) (49) (50) (51) (52) (54) (79) (82)	10	(26) (69) (73)	3	(6) (13) (24) (32) (46) (48) (54)	7	(43) (59) (60) (69) (81)	5	(2) (29) (57) (59) (63) (69) (70) (72) (81)	9

	(49) (53) (64) (72) (75) (76) (78) (80) (81)											
10. COMMUNICATION	(1) (7) (10) (11) (14) (21) (22) (30) (33) (36) (38) (41) (49) (53) (64) (71) (72) (75) (76) (78) (81)	21	(5) (27) (32) (50) (51) (52) (54) (56) (62) (79) (82)	11	(6) (73)	2	(6) (13) (32) (46) (54)	4	(43)	1	(2) (29) (70) (81)	4
11. RISK	(1) (7) (10) (11) (21) (22) (30) (36) (38) (49) (57) (64) (71) (75) (81)	15	(5) (6) (20) (27) (30) (32) (41) (46) (50) (51) (52) (54) (56) (79) (82) (83)	16	(26) (73)	2	(13) (24) (48) (54) (83)	5	(43) (60) (81)	3	(29) (63)	2
12. PROCUREMENT	(10) (11) (21) (30) (33) (49) (53)	9	(5) (20) (24) (27) (32) (41) (46) (49) (50)	16	(26) (41) (73)	3	(13) (17) (24) (46) (48) (54) (83)	7	(43) (60)	2		0

	(57) (75)		(51) (52) (54) (56) (79) (82) (83)									
13. STAKEHOLDER	(1) (7) (10) (11) (19) (21) (22) (28) (30) (33) (38) (41) (49) (53) (57) (64) (72) (75) (76) (80)	15	(5) (17) (20) (24) (27) (32) (37) (41) (46) (48) (49) (50) (51) (52) (54) (56) (62) (79) (82)	19	(6) (73)	2	(6) (13) (24) (41) (46) (54) (59) (72) (83) (83)	7	(43) (60)	2	(29) (63) (70)	3
14. HEALTH, SAFETY, SECURITY (HS) & ENVIRONMENTAL	(1) (10) (11) (22) (28) (30) (36) (38) (49) (53) (71) (75) (76) (78) (81)	15	(32) (54) (79) (82)	4	(17) (26) (51) (73)	4	(46) (48)	2	(43) (81)	2	(2) (29) (41) (57) (59) (63) (70) (72) (81)	9
15. FINANCIAL	(10) (11) (30)	3	(5) (27) (32) (51) (54) (79) (82)	7		0	(13) (83)	2	(43) (59)	2		0
TOTAL		**196**		**146**		**43**		**73**		**39**		**53**

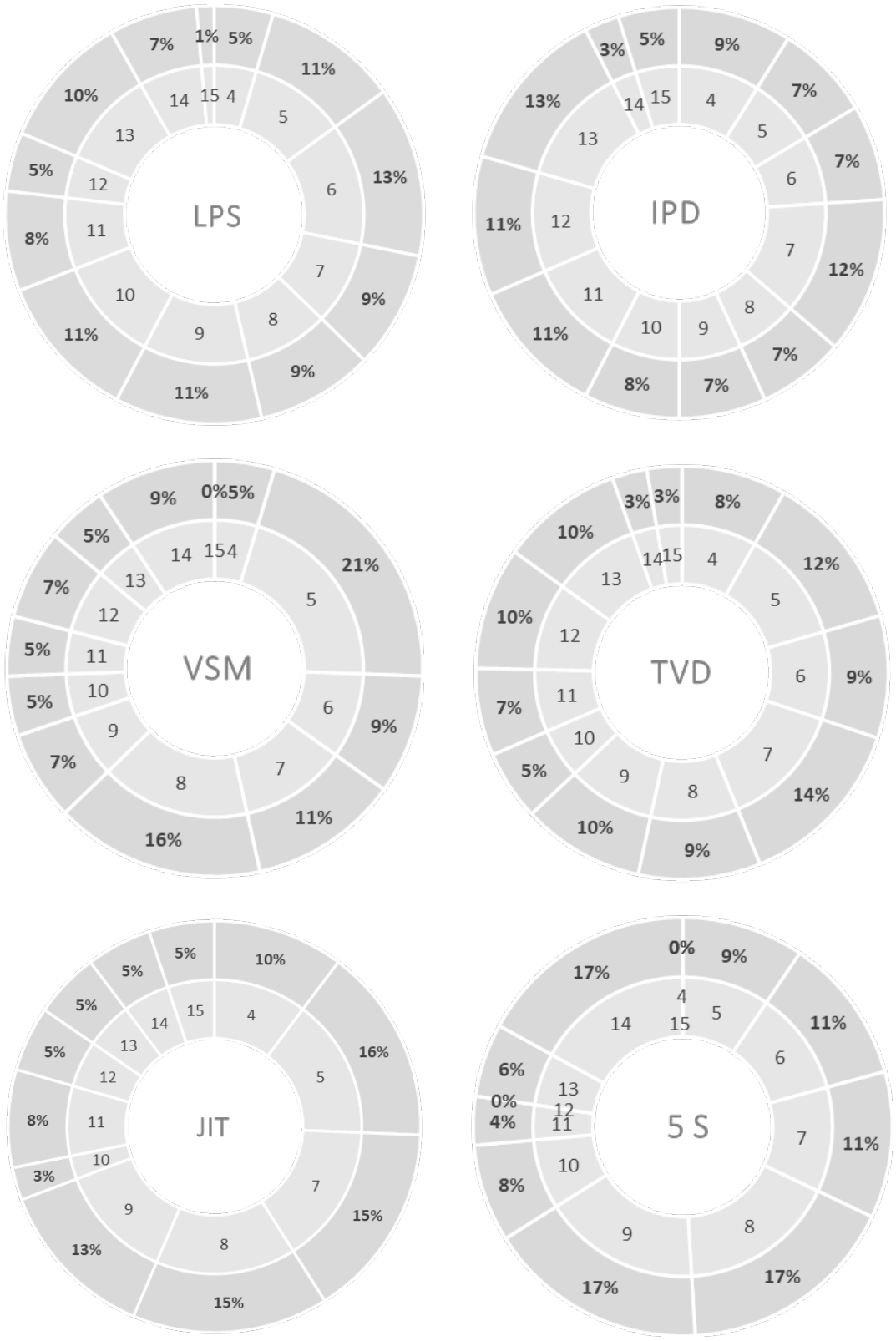

Figure 5. PMKAs percentage of improvement for each LC tool based on table 3.