Construction and Demolition Waste—A Shift Toward Lean Construction and Building Information Model

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Abstract

Waste in the construction industry is a devastating dilemma, especially that construction and demolition activities are considered as the highest waste generator globally. Countries have developed regulations: policy-makers and professional associations have provided norms and policies to manage C&D waste. Previous studies, however, have revealed insufficiencies in the current regulations and norms in incentivizing the industry practices toward waste prevention, since its culture is characterized by the gap in technological use, insufficient knowledge, poor planning, and poor information flow. This research provides a literature review on the current research findings and trends in managing C&D waste. Then based on design theory and theory of production, an exploratory research consisting of BIM and Lean construction concepts is provided. Lean can maximize the value of construction by addressing waste within portfolios, projects, and operations; BIM offers an enhanced collaborative platform with improved design practice and information management throughout buildings' life cycle. The proposed conceptual framework enables economic, environmental, and social benefits to allow practitioners collaborate, analyze, and minimize construction waste throughout buildings' life cycle.

Keywords

C&D waste • Production theory • Computer-Aided design • Lean

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1 Introduction

Construction and demolition (C&D) waste stream is defined as a mixture of debris materials generated from construction, rehabilitation, renovation, demolition, and deconstruction processes (Shen et al. 2004). The industry is severely confronted with its negative economic, environmental, and social impacts throughout the whole building life cycle. The problem of C&D waste generates the highest waste rates compared with other industries (Yuan and Shen 2011), for example, the United States disposed around 500 million tons in 2014 (EPA 2017). Likewise, in the United Kingdom, C&D activities contribute over 120 million tons yearly (WRAP 2007). The Portuguese construction industry estimated to generate 100 million tons of C&D waste globally (APA 2018). Therefore, developing strategies and campaigns in order to manage C&D waste is becoming urgently required by (governments, policy-makers, professional associations, and organizations). For example, EU has released incentives such as Directive Number 2008/63/EC to present a new understanding of C&D management to prevent virgin materials depletion, preserve landfilling sites, reduce Co_2 emission, and increase recyclables use (European Parliament 2008). The European Union has also proposed a circular economy plan in 2015, in which a waste management plan is included to embedding closed-loop approach to the industry practices with increased reuse and recycling rates within the industry projects (European Commission 2018). Nonetheless, the current regulations do not sufficiently incentivize owners, contractors, subcontractors, and providers to take preventive actions to eliminate waste generation before it arises. Because the end of pipe treatment approach is not enough to change the traditional construction culture toward waste prevention mindset (Osmani et al. 2008). In addition to these best practices guide require several technical, managerial, and economic factors that were not considered within construction waste management: such as planning, designing out waste, communication and

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collaboration between different stakeholders (Crawford et al. 2017; Jaillon et al. 2009; Poon et al. 2004). Waste management is *a sui generis* discipline that cannot be isolated from production, social, and economic theories. Since that construction processes would change with long-term preventive and corrective countermeasures, to cultivate individual commitment toward waste reduction and assign responsibilities between trades. C&D waste is interdisciplinary phenomena, and its research is usually motivated by environmental and social and economic drivers; enormous established literature have identified considerable C&D waste management theories, methods, and techniques from engineering, technological, managerial, social sciences, economical and policy backgrounds (Jin et al. 2019).

This paper is organized into three folds: first fold is exploring the journey of C&D waste development through compiling the highest cited literature. Second fold, a description for methodology used in order to answer the research question. Third, a conceptual framework is provided based on Lean principles and BIM functionalities in aim to collaboratively limit the negative impact of C&D waste at source. Finally, conclusions and further research insights are drawn.

2 Methodology

The extensive literature review was performed based on Webster and Watson method to define and identify the concepts related to research in order to understand the significance of information, in the domain of Lean construction, BIM, and C&D waste management published in Scopus between (2000–2019) (Webster and Watson 2002). Then this research attempts to demonstrate the key related publications by classifying the emerging literature based on matching citations to their category and upon the keywords criteria. Later research investigation separates and explains the literature to understand the current industry practice for each concept within the study boundaries. Following with synthesizes and combining BIM functionalities and Lean construction principles to support the implementation of Just-in-time and Last planner system (LPS) aids in C&D waste management strategies. Finally, an evaluation for the selected reviews is performed to connect, decide, support, and concluding the viability of each principle from the perspective of C&D waste management across in design and planning stages.

3 Results

3.1 Quantification and Estimation of C&D Waste

The quantification for C&D waste has been discussed within waste management arenas, which aims to measure, track, and benchmark waste that allows for stakeholders to quantitively increase certainty for projects planning for C&D waste to enable comparisons between different scenarios of waste generation (Katz and Baum 2011). Additionally, materials waste generation levels rely on its composition, thus federated C&D waste classification is required, such as European Waste List (EWL) which is a notable potent incentive to statistically identify waste at source and match its numerical measurements (European Parliament 2008; Llatas 2011). Waste estimations and quantifications were provided based on several methods including site visit (Jaillon et al. 2009; Poon et al. 2004; Formoso et al. 2002), accumulation methods (Jalali 2007; Sarhan et al. 2011; Solís-Guzmán et al. 2009), Material Flow Analysis (MFA) (Cochran and Townsend 2010; Hashimoto et al. 2007), and calculations based on generation rates (Banias et al. 2011; Coelho and De Brito 2011). Computer-aided quantification tools were used to facilitate accurate calculations. Jalali (2007) has utilized Microsoft Excel spreadsheets to perform analysis on building systems components. SmartWaste™ (2010). is a web-based platform for C&D waste forecasting based on interpolations of historical projects database. Cheng and Ma have introduced BIM-based quantification model in order to facilitate charging fees, pickup frequency, and reusing or recycling rates (Cheng and Ma 2013). Nevertheless, these estimation methods are hindered by the inaccurate statistical database, and lack of validation which make them impractical.

3.2 Emerging Technologies in AEC

The advancements in development of information technologies have endeavored number innovations to Architecture, Engineering, and Construction (AEC) industry. Enormous technologies were embedded to building design along with arising incorporation of BIM within industry practice processes; including, on-site management, risk assessment, and mitigation, functional simulations, 4D planning and detecting clashes, etc. (Di Giuda and Villa 2015). The research has expanded the ontology of BIM toward C&D waste management; earlier investigations for the potentials of BIM in CWM field has explored that tools such, clash detection, rapid generation of design documents, online clouds, and 4D site planning; would contribute better information flow between suppliers, trades, and contractors, and decrease rework and effect last minute change from client (Liu et al. 2011). In order to plan waste computationally, (Cheng and Ma 2013) has proposed a method to calculate pickups, landfilling fees, and 3R rates (Cheng and Ma 2013). Bilal et al. (Bilal et al. 2016) have applied Big data in order to enrich the ontology of BIM by Waste Generation Rates (WGR) and therefore build a reliable and accurate calculations based on query languages (Bilal et al. 2016; Lu et al. 2017). Another data collection tool was used in order to acquire existing buildings information. Ge et al. (Ge et al. 2017) employed laser scanning tool using digital photogrammetry to reconstruct BIM for existing building (2017). The literature emphasizes the advancements of IT in the industry stakeholders to providing the optimal alternatives for C&D waste management.

3.3 What Is the Role of Theory of Production in Overcoming C&D Waste Problem?

The theory of production in construction Koskela (2000) has emerged revolutionary models of thoughts concerning construction processes, and it has shifted the research to focus on the flow instead of the process-oriented research; the decomposition of transformation, flow, value (TFV) theory has decomposed the processes into interdependent subprocesses that allow practitioners to understand the production in process manner rather than evaluating the construction solely through results-driven approach. The flow in construction is explained by Sacks as (process creating the product) the physical building floors or spaces and (operations composed of workers and equipment) the typical construction resources trade crews, formworks, cranes, materials, etc. (Sacks 2016). The way of creation of spaces or floors needs interactions between operators, equipment, and materials; C&D waste principles are thus embedded within this transformation, and this can be applied through reusing left-over materials from former space to latter spaces, then adding chutes at every floor in order to segregate the waste that cannot be reused (Poon et al. 2001). Therefore, as crews are moving between spaces could collect waste and reuse, and also chutes would decrease the likelihood of mixed waste generation.

The core principle of being Lean is the view of workflow to create pull flow, to increase throughput time (TH), reduce work in progress (WIP), cycle time (CT), and batch sizes; as a result of minimizations for non-value-added activities in the value stream including waiting, inspection and reworks (Shah and Ward 2003). A proper application of Lean construction; would decrease the materials loss on one hand, and reductions in WIP would reduce reworks and material breakage, thus it will eliminate the root causes for C&D waste. On the other hand, supply chain task would be empowered by applying Just-in-Time (JIT), when the material arrives to the site only when needed to commence the desired task, this will reduce stock piles in the site and will be less prone to deterioration of material by equipment and crews movement, hence JIT may deliver more stable materials flow prior to processing of production units in the construction site. This could be extended also to movement of equipment such as cranes, loaders, etc. to deliver more efficient performance and less malfunctions (Kirchbach et al. 2013).

Visual management (VM) is an essential Lean tool that raise awareness and communicate information between stakeholders; an effective VM constitutes interaction between traditional and IT-based information and ontology management (Tezel and Aziz 2017). Along with the development of information technologies would support the VM role in enhancing social behavior in adapting with Lean principles. Therefore, C&D waste could be managed by the application for VM in the site to emphasize the segregations or through drawings hanged on site boards to raise the awareness to predefined C&D waste strategies. Another Lean practice is Gemba: Gemba is walking between operations over the process of production to conceive understanding for waste causes and influence the role of inspection for defects, therefore waste root causes (Ohno 1988), and this could enhance data rigor by embodied facts. Gemba walk is not only influencing production rates, but also C&D management by involving the managers to see by themselves what operations are causing waste? and which supplier provides resources in improper specification, time, and packaging, etc.? How process is generating waste? Gemba walk is the main motivation to perform root cause analysis by involving top management in the process to identify the waste and then share the results with the team to find the countermeasures to solve the waste at source.

3.4 Building Information Modeling (BIM)

"BIM is the process of generating and managing facilities within digital representations of physical and functional characteristics building information in an interoperable" (Eastman et al. 2011; NBS 2015). BIM also has tools that constitute ground foundation for building automation and data exchange platforms, which ensures better workflow and enhanced visualization. BIM is a reliable technology and process to computationally and collaboratively coordinate the building over the whole life cycle. For example, the research has expanded the usage of BIM to end-life scenarios (Volk et al. 2014); deconstruction plans may obtained from BIM, since there is an evidence in the capability of BIM functionalities to provide end of scenario analysis (Akinade et al. 2015). As well as, the interoperability between BIM software program has been validated to produce a deconstruction plan for demolition waste analysis purposes (Ge et al. 2017; Volk et al. 2018). Furthermore, the incorporation between Lean construction and BIM interactions has been identified as the integration matrix with 50 positive and 3 negative interactions (Sacks et al. 2010). This implies that Lean construction and BIM complement each other in engineering practice, the former constitute fundamental management paradigm for production in construction and latter is the foremost technology that support the streamline of the information management and visualizations to support the planning certainty and production stability.

Virtual Design and Construction (VDC) is a Lean BIM systematic methodology that comprises the building and updates the BIM model virtually, and performs simulations and analyzes for its performance in the design stage, and then prepare the planning and remove constraints based on BIM model in iterations of appraisal and refinements; finally, building the construction from BIM model, to monitor the performance of the building in reality and feedback BIM model for as-built (Sacks et al. 2017). In those iterations, C&D waste management plans can be reviewed and updated through involving clients, owners, contractors, and subcontractors throughout the design and construction development. In adoption of Lean construction and BIM within the industry projects and further to operations; the cognition of waste root causes could be detected and analyzed collaboratively with association in comparisons for design and construction or deconstruction methods through performance analysis.

The lean thinking in construction has been adapted from manufacturing, since several tools were tailored to meet the peculiarities of the conventional construction production management. Lean construction toolkit includes Last planner system® (LPS), (JIT), 5S, and so on (Paez et al. 2005). Based on Lean paradigm, the effective control system should capture the requirements of the client and translate them to efficient processes, that consist of added value interactions between smoothened flows to reflect the exact need of customer (Ohno 1988). In order to provide leaner construction processes, it is essential to investigate the root causes of waste; using various investigation and analysis methods, techniques and tools, that allow project participants with taking proactive and tactical actions to reduce various facets of waste. To improve the productivity.

3.5 The Conceptual Framework

The inspiration of this framework stems from the production management prototypes of (Sacks et al. 2010) followed by the visual production system of Lin and Golparvar-Fard (2018), (Sacks et al. 2010). This framework aims at limiting the negative impact of waste generation during a construction project, by leveraging BIM in visualizing the process and product for buildings and harnessing the capabilities of BIM functionalities to supporting the principles of Lean construction (See Fig. 1).

3.5.1 Last Planner System (LPS)

To ensure the delivery at the right time, the production system has to predict the right amounts of resources to be effectively utilized by each task, this can be applied using LPS by planning and controlling work packages collaboratively. To overcome the black boxes issue that encapsulated inside the traditional CPM charts, LPS aims at improving the reliability of planning through refining decision-making at several levels (Ballard 2000). The advantage of LPS for JIT is measuring and tracking quantitively and qualitatively the compliance for suppliers and trades with planned activities, in addition, LPS shielding downstream by providing reliable plans and optimizing materials on long-term basis; that allows activities to be commenced only if constraints were removed (Sacks et al. 2010). The quantitative measure in LPS system is Percent Plan Complete (PPC); this measure is held in weekly work planning meetings, which calculates the level of planning reliability and allows planners to decide the commitment level of specific trade subcontractors.

BIM supports the weekly and daily meetings, by visualizing the process/product and detecting the conflicts between trades (Eastman et al. 2011). Additionally, BIM commercial software can generate accurate quantitative reports for building materials that allow planners, engineers, and trades to estimate factors such as duration, constructability, delivery, and so on. Sacks et al. (2010) stressed on the positive impact of BIM on learning curve during LPS meetings; and when meeting participants can predict and assess the risk of alternatives before moving to the site. However, the current research has developed and verified production controls using LPS during construction stages, but it has little attention on its implantations for demolition operations.

3.5.2 Just-in-Time (JIT)

The Lean thinking-based JIT principle was invented and first implemented in Toyota Production System (TPS), JIT stands for "*a system producing and delivering the right items at right time in the right amounts*" (Womack and Jones 2003).

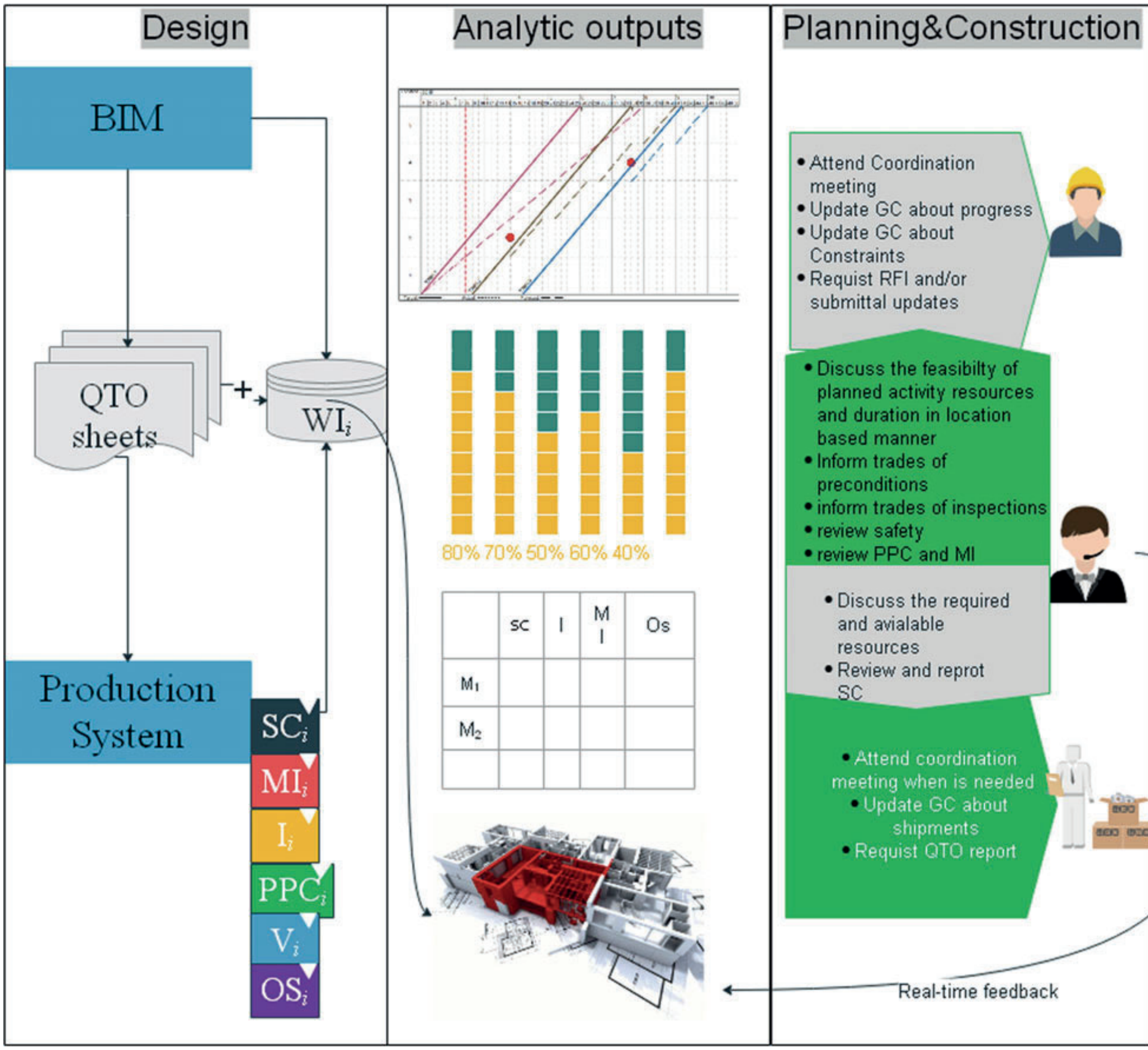

Fig. 1 C&D waste mangement conceptual framework based on Lean construction tools and BIM functionalities *SC: Supplier commitment*MI: Tasks maturity index*I: Inventory reliability *PPC: Percent Process Complete *V: Vehicles arrangements and availability *OS: Onsite sorting as part of site layout planning

Ideally, successful JIT should pull tasks and resources from schedule, reduce inventories, consider the flow stream, and standardize workflow; specifically, when operating repetitive tasks from the schedule, therefore, the workflow will be smoothening and associated with reduced conflicts between trades into spaces or locations. Paez et al. (2005) considered JIT as an imperative part of Kanban system, by pulling materials from the suppliers to inventory or site based on Kanban signals (Paez et al. 2005).

The flow of materials should be pulled from the schedule, based on the Daily Work Meeting (DWM), in addition to the accessibility to the model to review BIM material can allow participants to review the progress; and plan for arrangements of vehicles depending on Kanban signals. The interoperability between BIM and resources' control systems can be achieved (Table 1), so procurement information can be exchanged interchangeably, which reduces the risk of variations between planned and ordered quantities, moreover, that would be stabilizing the information for material flow.

3.5.3 Line of Balance (LOB)

The variation within processes results in discontinuous or interrupted flows due to conflicts between trades in location, time, or resources, therefore, variation is considered as a major cause of waste generation in construction projects as

Table 1 The key factors of waste reduction framework using JIT based on underlying production theory and BIM

JIT principle	Derived principles of LC				BIM capabilities		
	PPC	MI	PI	I	LOB	QTO	4D planning
Right time	√	√	√	√			√
Right amount	√	√	√	√	√	√	√
Right items	√	√	√	√	√	√	√

*JIT: Just-In-Time
*PPC: Percent Plan Complete to support Last Planner System©
*LOB: Line of Balance
*QTO: Quantity Take-off
*MI: Maturity of tasks
*PI: Provider commitment
*I: Inventory capability

reported by Tommelein et al. (2002). The method CPM scheduling would be useful for the first stages of LPS, specifically, it supports the reverse planning in master scheduling. However, Sacks et al. (2017) have criticized the use of CPM represented with Gant charts for advanced levels of LPS, since they encapsulate the information inside charts without emphasizing the details about trades and locations clashes (Sacks et al. 2017). Location-based scheduling is the adaptation of Line Of Balance (LOB) from the manufacturing industry. Björnfot and Jongeling (2007) have appraised location-based scheduling technique with the aid of 4D BIM, and they found that location-based planning would minimize variations and allow planners to detect flow distribution. Therefore, LOB and 4D CAD would add spatial insights for model developers and planners to identify congested sites and predict inefficient use of materials by synchronization of activities using 4D model (Björnfot and Jongeling 2007).

4 Discussion

The construction and demolition waste is still a damaging issue, aligned with the expansion of construction market. This indicates the need for integrated systems that can reduce waste and improve the productivity. The literature has investigated lean manufacturing adaptation into the construction industry, but there are still some inefficiencies in the industry production systems due to the complexity of operations and the strong reliance on various stakeholders in separated locations (Lin and Golparvar-Fard 2018).

The current construction and demolition waste management methods have shown their inefficiency in minimizing waste. Lean construction aims at waste reduction from processes to provide higher value to the customer [51]. Lean construction systems provide set of tools and methodologies such as LPS and JIT, the former helps trades to reduce variability in production and shield the downstream from several types of wastes, the latter aims at ensuring the appropriate use of resources in the project when controlling time, items, and space. On other hand, BIM platforms offer accurate reports regarding the materials and building systems, which allows stakeholders to take decision on design before commencing construction, and provide reduced reworks, design iterations, and process/product visualization (Sacks et al. 2010). This study explored these Lean and BIM concepts to minimize the waste at source that can enhance the planning and design assessment for optimization during weekly or daily LPS meetings.

The provided conceptual framework explored the capabilities of incorporated Lean and BIM to assist contractors, designers, suppliers, and trades to focus on material optimization. The integration of Lean and BIM also incorporates the importance of supplier and trades commitment, inventory arrangements, the precision of material reports, the maturity of tasks with defining preconditions, and analyzing the constraints, on-site sorting as a part of site layout planning and vehicles management. This framework has been built on evidence from literature survey, which found that BIM functionalities can predict and analyze several types of waste in construction process flows (material, time, labor, and space) when utilizing Line of Balance for repetitive tasks.

In view of this, the Lean and BIM framework has a considerable potential for improving construction and for demolition waste management by offering collaborative platform using factors that have been tested in previous research in the context of resources optimization [52]. This framework will assist project teams in conceiving the implications of design and planning on the construction and demolition processes. Also, studies will investigate the applicability of the proposed framework on the overall construction and demolition teams meeting to minimize wastage level and embed those tools to BIM commercial software.

5 Concluding Remarks

This study provided a conceptual framework based on integrations between Lean construction principles and BIM functionalities to develop design and planning system for material optimization, and factors were explored and identified to the overall framework. The study has proposed tools from Lean construction such as JIT, LPS, and location-based planning, and capabilities of BIM in providing Quantity take-off reports and integrates them to 4D planning. The study identified that important success factors are (1) supplier commitment for JIT, (2) trades commitment for LPS meeting, (3) work only on matured and refined tasks, (4) Inventory management, (5) site layout planning including on-site sorting methods, (6) the dependencies of other flows of equipment and labors in the site.

The key success factors for this framework would be benefits for project teams (designers, contractors, trades, and suppliers). The results of this research should be communicated with industry practitioners in order to prioritize them, followed by incorporation to BIM platforms by using application programming interface (API) and tested in real-world operations. The prospected results from future research are analytical and predicting platforms that can assist stakeholders to take decision in waste reduction strategies. Besides the limitation of verification for this framework, the future research should focus on capturing requirements for end-of-life stages in order to provide a comprehensive C&D waste management methodology.

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