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ADVANCING AEC PROJECT MANAGEMENT: A MODEL-BASED AND DATA-DRIVEN APPROACH FOR SUSTAINABLE PRACTICES

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Abstract

The construction industry is transitioning from traditional linear methodologies to the Total Life Cycle Process (TLCP) based on DIN EN ISO 19650 principles. TLCP employs database-supported information models (dIMs) and Information Requirement Matrices (IRMs) to enhance project management, focusing on sustainability. This method improves communication, ensures timely access to critical information and optimizes resource use. By integrating the Level of Information Need (LOIN) concept and web-based tools, TLCP supports agile transitions and technological adaptation. This paper showcases TLCP's practical applications, promoting sustainable construction management and encouraging industry-wide discourse, ultimately contributing to long-term environmental and economic benefits.

Introduction

The construction industry has focused on conserving resources in recent years to align with the Sustainable Development Goals (SDGs) (United Nations, 2023) and the Green Deal (European Commission, 2023). The Green Deal promotes forward-thinking actions and responsible resource management through terms such as sustainable production and sustainable decisions. These terms serve as specialized language. The importance of forward-looking planning and conscientious resource utilization is emphasised by these terms. A comprehensive strategy for managing raw materials is presented, which emphasizes savings while also promoting reuse and reduction of excess, such as construction waste. Although foundational elements in the construction industry, the sustainability factor involved in action and decision-making has not received enough attention in public discourse, despite its critical role in achieving the aforementioned goals.

The state of disrepair in infrastructure (Norddeutscher Rundfunk, 2023) has long been a public concern. The list of reasons for recent failures highlights structural flaws in the industry that neglect the life cycles of infrastructure such as bridges, roads, and railways. It is crucial to understand the temporal significance of structures and their relationship with sustainability. Infrastructure should not be viewed as disposable, but rather as part of a recurring cycle. They should not be forgotten once built. Adherence to academic norms, objectivity, and formal language is essential. The object life cycle can be divided into five phases: initiation (0), planning (1), execution (2), operation (3), and optimized initiation renewal (4). However, as the physical existence of the object is limited to phases 2 and 3, the term project life cycle is used to emphasize its place within the broader process. Sustainability is an important consideration in project management, which involves the overall execution of projects. Project management provides a more comprehensive framework for considering sustainability compared to the project life cycle.

This study aims to establish links between temporal processes and modern digitisation techniques. Additionally, this paper proposes a novel approach to developing project-specific temporal processes. This will result in clearly defined tasks that enhance project management in the construction industry. The ultimate goal is to contribute to the long-term sustainability and future prospects of the German construction sector through the use of TLCP.

Sustainability integration in lifecycle processes

In contemporary discourse, sustainability is moving beyond its traditional definition to become a multifaceted concept, often divided into three domains: economic, environmental and social (von Hauff et al., 2005). Current research efforts focus on effectively integrating these domains within work systems to facilitate concerted action, taking into account both immediate and future impacts. This holistic approach to sustainability, often referred to as the sustainable polygon, requires a thorough understanding of the underlying mechanisms, which requires iterative development and analysis in real-world contexts for practical applicability (Flemisch et al., 2023).

Skilled planners play a crucial role in the efficient use of available resources to achieve cost effectiveness in building construction, while ensuring suitability throughout the life cycle. This involves careful consideration of materials, processes and responsible resource management over the life of the building. In Germany, the Fee Structure for Architects and Engineers (HOAI) further delineates these phases, resulting in up to ten phase levels, with phase (0) serving as an initialisation or preliminary feasibility study.

However, this traditional approach to project billing in Germany has its limitations, particularly in addressing gaps and information loss during project execution, given the iterative life cycle of products and technological advances such as model-based computer systems and

Building Information Modelling (BIM). Several factors contribute to these shortcomings, including compliance with regulatory requirements, prioritisation of social needs over technical optimisation, and challenges such as lack of digitisation, transparency and effective communication (Weber-Lewerenz, 2021).

Figure 1: Stages within the project Management

Integrating sustainability principles into project management practices is essential to promote project sustainability. According to the German National Standard (DIN) 69901-5 (DIN e.V., 2023), project management encompasses various tasks, techniques and means necessary for initiating, defining, planning, controlling, coordinating and completing projects. This includes overseeing phases (0)-(3) of the product lifecycle, as shown in Figure 1. However, project management responsibility typically only extends to the end of the warranty period of the contracted services in phase (3).

Efforts to embed sustainability in project management include the simultaneous consideration of economic efficiency, material selection and social aspects (Silvius, 2017). For example, during the planning phase, conducting a product life cycle analysis can help assess the impact of actions on the three pillars of sustainability. Project management plays a critical role in either analysing the impact of sustainability measures or coordinating their implementation (Project Management Institute, 2021).

Holzbauer et al. (2021) further categorize sustainability processes in project management into three areas: internal processes, management of projects, and project-specific processes. Emphasizing a broader perspective on projects, sustainability in project management entails coordinating the overall process, networking internal and external influences, and applying known sustainability principles (Stumpf et al., 2012).

Sustainability in project management practices

To effectively embed sustainability into project management practices, it is imperative to adopt a comprehensive approach that encompasses various aspects of project execution. This involves integrating sustainability considerations into internal processes, such as resource allocation and risk management, to ensure that economic, ecological, and social factors are adequately addressed throughout the project lifecycle. Moreover, managing projects with sustainability in mind requires proactive measures to minimize environmental impact, promote social equity, and optimize economic viability.

Project-specific sustainability processes entail tailoring sustainability initiatives to meet the unique requirements of each project. This may involve conducting thorough assessments of environmental impact, implementing green building practices, and fostering stakeholder engagement to ensure alignment with sustainability goals. By incorporating sustainability principles into project management practices, organizations can enhance their reputation, reduce costs, and contribute to long-term environmental and social well-being.

In conclusion, sustainability in project management is integral to achieving lasting success in today's dynamic business environment. By integrating sustainability considerations into project planning, execution, and evaluation, organizations can mitigate risks, capitalize on opportunities, and create value for stakeholders. Through collaborative efforts and strategic initiatives, project managers can drive positive change and foster sustainable development for future generations.

Managing Information Transfer Complexity in AEC Projects

Effective information transfer is crucial for the success of AEC projects, yet it often presents significant challenges due to the multifaceted nature of project requirements and stakeholder involvement. This subsection delves into the various facets of managing information transfer complexity within AEC projects, highlighting key considerations and strategies for addressing these challenges with a focus on the German construction industry.

Navigating the regulatory landscape, including frameworks such as the HOAI, introduces complexities in information transfer processes. Compliance with regulatory requirements adds layers of intricacy to data exchange, necessitating clear understanding and adherence to legal standards. Moreover, ambiguity in information requirements further complicates the transfer process, as stakeholders may struggle to discern the specific data needed for each project phase. This ambiguity can result in inefficiencies and delays, underscoring the importance of clarifying information needs and ensuring compliance with regulatory guidelines (Mohan et al., 2021).

Effective information transfer hinges on seamless collaboration among project stakeholders, including architects, engineers, contractors, and clients. protocols ensure consistency and accuracy in data transfer, reducing the risk of errors and discrepancies. Additionally, digital tools and technologies, such as

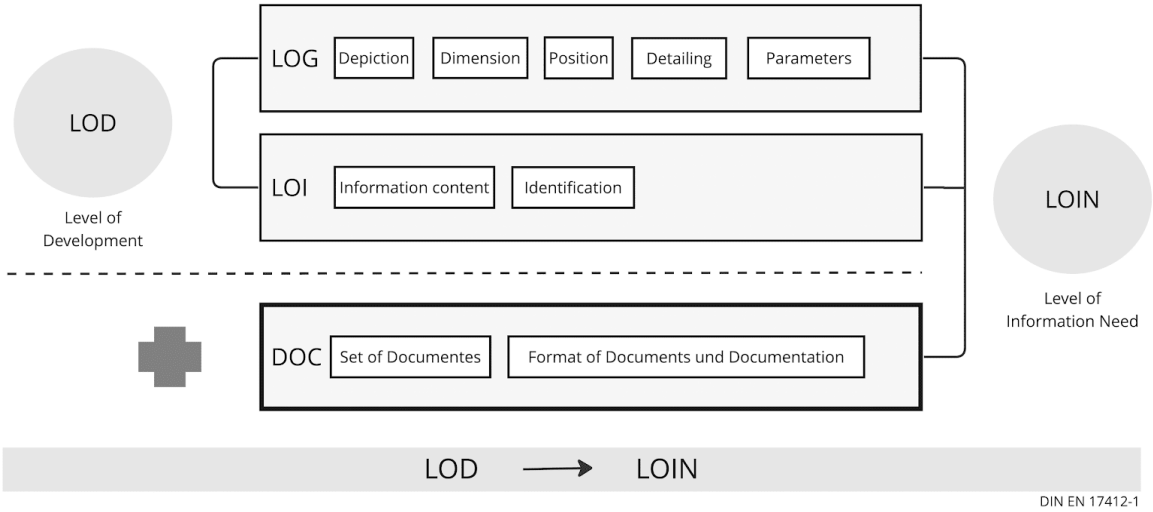

Figure 2: Level of Information Need (LOIN) (DIN e.V., 2023)

Coordinating diverse teams and aligning their efforts towards shared project goals requires robust communication channels and established information-sharing protocols. Clear delineation of roles and responsibilities, along with regular communication and collaboration platforms, fosters synergy among stakeholders, facilitating the smooth flow of information throughout the project lifecycle.
As all project participants have different starting points, it is essential to have a defined digital knowledge transfer to ensure accurate and transparent information transfer.

Building Information Modelling (BIM) software, offer advanced capabilities for visualizing project data and facilitating collaborative decision-making, further enhancing the efficiency of information transfer processes (Vaatz et al., 2023).
Implementing the TLCP not only provides a comprehensive view of the product lifecycle in the AEC industry but also offers a strategic approach towards sustainable project management. Through a dIM, TLCP facilitates the structured capture, management, and exchange of project-relevant information, ensuring its availability and quality while fostering efficient

Table 1: Table 1: IRM concept based on LOIN use case with consideration of TLCP (Mohan et al., 2023)

Key Data	Content
Use Case	Why is the information required?
Milestone	When is the information required?
Objects	What / *Which Information* is required? (LOG/LOI/DOC)
Actors	Who required the information?
	Who delivers the information?

Implementation of Digital Knowledge Transfer Solutions and the Effect of TLCP

In response to the challenges posed by information transfer complexity, digital knowledge transfer solutions emerge as indispensable tools for streamlining communication and data exchange. Centralized databases and information management systems provide a centralized repository for project-related information, enabling real-time updates and seamless accessibility for all stakeholders. Standardized information formats and

communication, transparency, and collaboration among all stakeholders.
Real-time updates and easy accessibility of information in the dIM significantly enhance decision-making and planning accuracy, which are essential components in sustainable project management practices.

Incorporating sustainability principles into TLCP, Table 1 and Figure 2 outline the IRM and its components, such as Level of Geometry (LOG), Level of Information (LOI), and Documentation (DOC), forming the foundation for managing the dIM. Informed by insights gleaned from past and ongoing projects, TLCP development underscores the importance of standardized information requests and effective communication channels in sustainable project management efforts.

Table 2: IRM for Infrastructure se case with consideration of TLCP

Key Data	Information Requirements Matrix (Infrastructure)
Use Case	Position of road alignment
Milestone	Preliminary Design to Conceptual Design
Objects	LOG: Geology, hydrography data, environmental constraints, protected areas details, As-is information, information from previous phases (As-is, Feasibility, alternative variations) LOI: Weather data, socio-economic aspects related information, cost-time analysis, infrastructure and utilities, national standards and guidelines, material details, construction phase considerations DOC: Explanatory report, soil report, construction phase line report, safety report
Actors	From Preliminary Design (Who delivers): Owner (Public/Private), Legal& state bodies such as state-approved surveying and information department, specialist/consultant, Fire protection expert, energy suppliers In Conceptual Design (Who requires): Planners, Owners, state authority, civic bodies, energy suppliers

By defining appropriate LOIN use cases adhering to DIN EN 17412-1 (DIN e.V., 2023), TLCP establishes an organized information delivery system for inter-project phase processes, thereby minimizing the risk of unnecessary iteration loops and information gaps. The forthcoming dissemination of LOIN use cases through web-based platforms will adhere to established requirements, foster interdisciplinary collaboration, and ensure consistent scrutiny of information delivery procedures, which are both integral to sustainable project management objectives.

In summary, the Total Life Cycle Process (TLCP) emerges as a fundamental framework for seamlessly integrating sustainability considerations into project management practices within the Architecture, Engineering, and Construction (AEC) industry. By facilitating efficient information management, fostering collaboration, and enabling informed decision-making, TLCP empowers stakeholders to navigate the intricacies of complex project lifecycles while upholding sustainable principles. This comprehensive approach not only ensures the development of environmentally responsible projects but also contributes to the creation of socially beneficial built environments.

Looking ahead, the forthcoming web-based dissemination of Level of Information Need (LOIN) use cases represents a significant advancement in enhancing information exchange efficiency within the AEC sector. Through TLCP, this initiative not only enhances the precision of information delivery but also encourages interdisciplinary collaboration across project phases. By leveraging TLCP's capabilities, organizations can elevate their project management practices, leading to improved outcomes and greater sustainability across the industry.

Proposed methodology

Implementing TLCP in the current process relies on key factors, including adherence to national and international standards, digitalization through information models, systematic derivation of Information Requirements, cross-phase methodology, agile transition, process optimization, and fostering discussion and exploration.

In the course of the study, it emerged that various approaches have developed in the different phases, which require different information requirements. One example from infrastructure planning depicted in Table 2 is that the information from the planning phase must be prepared in such a way that authorisation is possible based on the applicable technical and legal requirements.

Efficient integration of the TLCP process requires a meticulous consideration of not only the primary criteria for information requirements but also the often-overlooked sub-criteria and sub-sub-criteria. Failure to inspect these finer details can result in significant time loss. By adopting this comprehensive approach, TLCP has the potential to evolve beyond a mere project standard to become a standardized practice within the entire organization. This shift ensures a thorough and consistent application of TLCP principles, enhancing overall efficiency and effectiveness across diverse projects and initiatives.

Implementation and integration of TLCP in a web-based information modelling tool

Implementing and integrating life cycle processes in a web-based information-modelling tool is achieved following the steps shown in the process picture (Figure 3) below:

The first step towards implementation of TLCP in a web-based information modelling tool involves identifying and defining all the life cycle processes that are relevant to the project, tailor-made for each life cycle phase, such

as preliminary, conceptual, and detailed design, construction, maintenance, renovation, and demolition, among others. In this step, as listed in Table 2, the impacts, input and output, object types and actors with all inter- and outer relations must be defined in data and rule catalogues. Once the processes have been defined, they are to be modelled in the information modelling tools. After this stage, the data and information throughout the entire life cycle of the project would typically look like various islands, which in some cases are connected, and, in some cases, not, in which the data and information flow is not guaranteed during the entire life cycle.
The next step is to establish connections between the project is in a targeted way so that process-oriented information flow, collaboration and relevant communication is guaranteed. Such layouts can be purposed to target design, construction, operation and maintenance processes; transition processes; machine, human, and technology processes; or sustainability processes. The smart platforms have the capability to keep the information regularly updated and maintained to reflect changes over time with versioning and archiving mechanisms which is crucial especially in the operation, maintenance or renovation processes
In conclusion implementing and integrating TLCP in a web-based information modelling tool improves collaboration, provides more efficient processes, and

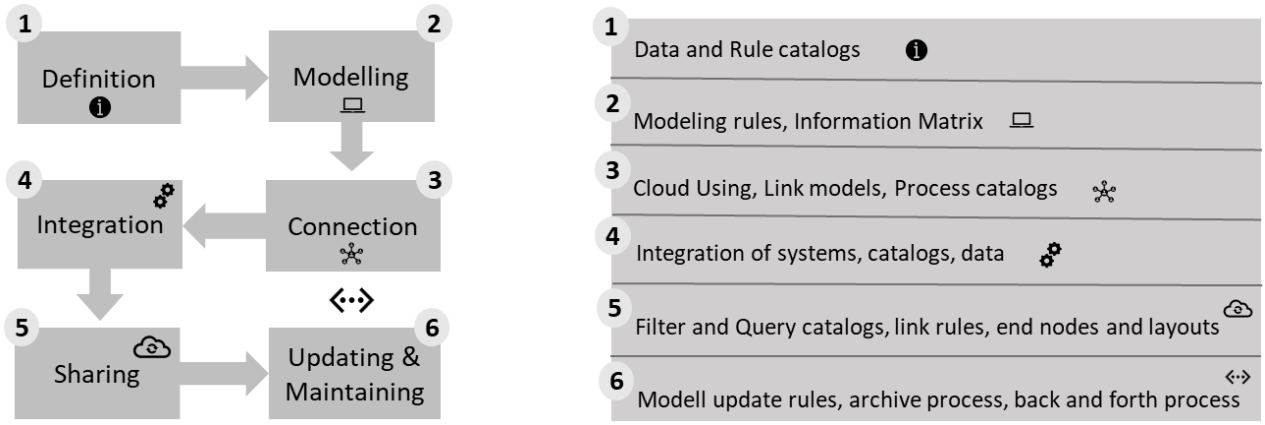

Figure 3: Integration of TLCP in a web-based information-modelling tool

different processes. This is typically done through a process flow diagram or a similar tool that shows how the processes interact with each other and with the building model in so-called process catalogues.
Therefore, in the next step, an integration platform should be designed to establish integration between different systems, such as project management systems or cost estimation tools for additional functionality. Web-based platforms are one of the best examples of such smart services in which nested information can be kept, interconnected and analysed based on integration catalogues.
Such web-based information modelling environments are from one side capable of parsing data and models, and interlinking information, and from the other side connect them to resources from manpower to machinery and collaboration between human and technology using Artificial Intelligence (AI) methods. By establishing such connections between various sources, a comprehensive overview of the project lifecycle not only in the planning and design stages but also in the construction, operation and maintenance is ensured. Once the integration platform is set, different layouts can be designed to host the query and filter catalogues and apply them to the nested information based on the profile specs along phases or in the transition processes. These layouts define which data are to be shared with whom and when based on what expectations and with which results. Thus, information sharing between stakeholders and parties involved in the better management of the project over its entire life cycle.

Conclusions and Outlook

The integration of different data sources and information models based on the TLCP is essential to increase efficiency and ultimately promote sustainability in construction. The information management applied enables systematic, evidence-based decision making across the design, construction and management domains, ensuring seamless data exchange and communication between the various project stakeholders across all phases. To improve the flow of information and ensure system interoperability, industry players need to collaborate more and establish common standards and data exchange formats. One promising option is the incorporation of artificial intelligence and machine learning, which could provide the potential for automating analysis and decision support systems in the future. Further research and pilot studies, as well as more widespread use in practice, will drive the development of this methodology and increase its usefulness and practicality.

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