Mapping Agentic AI Integration in the Circular Built Environment: A Systematic LoD Maturity Model

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Abstract. The circular built environment is characterized by dynamic building lifecycles, driven by heterogeneous material flows, iterative operational conditions, and multiple stakeholders. These requirements closely align with advances in emerging agentic Artificial Intelligence (AI) systems, enabling autonomous task decomposition, multi-tool reasoning, and feedback-driven adaptation. Despite rapid progress in autonomous multi-agent systems and digital twin (DT) intelligence, the integration of agentic AI into the circular built environment remains in its early stages. This study proposes an automated Level of Development (LoD) maturity assessment framework to evaluate the readiness of agentic AI workflows for circular construction applications. A two-phase systematic literature review was conducted to construct three research domains representing (1) agentic AI in the built environment, (2) circular construction, and (3) BIM/DT-based lifecycle digitalization. Cross-domain mapping revealed strong coupling between circularity and AI-enabled BIM/DT research, a developing trend between agentic AI and digitalization, and a limited intersection between agentic AI and circularity. The maturity classifications were mapped onto a LoD 100–500 scale, ranging from single-agent systems to autonomous frameworks. Initial maturity scores were generated using a large language model based on a six-dimensional (D1–D6) agentic maturity rubric covering agency structure, tool integration, reasoning depth, adaptivity, autonomy, and environmental data resolution. The outputs were assessed using an LLM-assisted consistency-checking procedure across rubric dimensions. The proposed framework provides a scalable approach to assess the readiness of agentic AI systems for the development of autonomous circular construction workflows

Keywords: Agentic Artificial Intelligence · Circular Construction · Multi-Agent Systems · BIM · Digital Twins · Maturity Assessment

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1 Introduction

Generative artificial intelligence (GenAI), particularly through large language models (LLMs), has initiated a new phase of transformation in architecture, engineering, and construction (AEC) through access to information, decision support, and workflow automation [1]. This transformation signifies not only the emergence of new tools but also the restructuring of knowledge-intensive, multi-stakeholder, and interdisciplinary construction processes. However, the use of these technologies in AEC carries significant limitations. Productions that are insufficiently grounded in domain knowledge can lead to problems such as hallucinations, contextual disconnection, unjustified decision-making, and outdated information [2]. These problems become more critical in BIM-based environments where structured data, classification systems, standards, and lifecycle-based decision approaches require co-working.

Research into reliable GenAI in the AEC is increasingly evolving toward retrieval-augmented generation (RAG) and agentic AI. RAG aims to improve factual accuracy and contextual appropriateness by grounding LLM outputs in external, validated information sources for information retrieval [3–5]. For the execution of more complex workflows, agentic AI enables task breakdown, tool handling, multi-agent coordination, memory management, and structured reasoning [1, 6]. Despite this progress, the use of agentic AI in circular construction remains limited and fragmented. Effective management of such processes requires AI systems capable of interpreting different data sources, evaluating decision alternatives, and operating adaptively throughout the lifecycle. BIM-DTs stand out as fundamental digital infrastructure that stores and updates circular construction information such as reuse of building components, material composition, component history, performance data, operational status, and end-of-life management [7].

Current research in agentic AI is concentrated in operational monitoring, DT simulation, smart building management, and auditing [8–10]. This shows a significant research gap that requires higher-level digital intelligence capable of interpreting data in context and translating it into lifecycle decisions. This study aims to address this gap by providing a Level of Development (LoD)-based maturity framework to evaluate the current maturity of agentic AI in circular construction. For this, the interdependencies among the agentic AI, circular economy, and BIM fields were examined. The results map the binary relationships between the fields and reinterpret the LoD concept through a maturity lens, enabling the co-reading of BIM data reliability and AI autonomy.

2 Method

The research has a threefold methodology including pairwise domain mapping across key research fields, LoD-based maturity classification through a lifecycle approach, and agentic AI maturity evaluation using a multidimensional rubric. The pairwise domain literature mapping is based on comparing dependencies of three emerging research domains within the built environment: (1) Agentic AI in construction; (2) Circular construction systems; (3) BIM-based digitalization using DTs. The proposed maturity evaluation framework, applied to the literature findings, aims to identify (i) how agentic AI systems interact with digital building data infrastructures and (ii) to what extent they support circular construction workflows.

2.1 Pairwise Domain Mapping

A pairwise domain mapping strategy was employed to analyze the relationships between the three domains: (1) Circular construction and AI-enabled BIM-DT; (2) Agentic AI and BIM-DT**;** and (3) Agentic AI and circular construction. These domains were compared to examine research developments across different levels of AI autonomy in digital infrastructure. The study first evaluated the two dominant pairwise relationships observed in the literature. The relationship between agentic AI and circular construction was found to be very limited and therefore treated as exploratory.

The literature dataset was compiled through systematic searches of Scopus, Web of Science, and IEEE Xplore. After screening and eligibility assessment, two subsets were extracted from the literature corpus. The first subset included 25 studies [11–35] where circular construction practices are operationalized through lifecycle digitalization platforms. These studies mainly focus on material tracking, lifecycle assessment, material passports, reuse planning, and deconstruction modeling. The second subset comprised 12 publications [36–47] focusing on autonomous AI systems characterized by capabilities of task decomposition, tool integration, multi-agent coordination, and adaptive reasoning.

This study reinterpreted the traditional geometric-based LoD scale as a dual maturity framework, linking BIM data reliability and agentic AI autonomy within circular construction workflows [48]. The Agentic LoD (ALoD) categories were interpreted across three circular construction lifecycle phases: early concept and design estimation, coordination and deconstruction planning, and autonomous material recovery and end-of-life management. The lifecycle phases are defined in Fig. 1 based on the combined progression of BIM data reliability and AI autonomy, and the maturity levels used to classify the review results are summarised in Table 1.

2.2 Agentic Maturity Rubric Evaluation

The technological maturity of the identified systems in emerging domains was evaluated using a six-dimensional agentic maturity rubric (D1-D6). The dimensions reflected the transition from traditional AI decision-support systems toward autonomous AI agents capable of operating across digital environments [1]. Using a six-dimensional agentic maturity rubric, each review finding was evaluated with LLM classification using a four-point scale (0–3), where 0 indicates the lowest or conceptual capability and 3 represents advanced implementations involving adaptive behavior, multi-agent coordination, or dynamic interaction with external digital environments.

The six-dimensional rubric used for study-level coding is presented in Table 2. For each finding, the dimensional scores were averaged to calculate the mean values. The mean values were then mapped to the ALoD maturity levels defined in Table 1 to position each finding in terms of technical agentic capability and its potential role in lifecycle-based circular construction workflows.

Table 1. Agentic LoD maturity levels and lifecycle interpretation

Maturity level	Label	ALoD	Interpretation
0	No agentic capability	Below ALoD	Review, conceptual mapping, and evidence of digitalization without an autonomous system.
1	Analytical decision-support systems	ALoD 100–200	Single model, DSS, basic tool-supported analysis; human is the primary decision-maker
2	Coordinated computational workflows	ALoD 300	Integrated BIM/DT/robotics workflow supporting structured automation, reuse assessment, and deconstruction planning.
3	Advanced agentic autonomy	ALoD 400–500	High integration with adaptive, robotic, DT-enabled, self-managed execution for autonomous management.

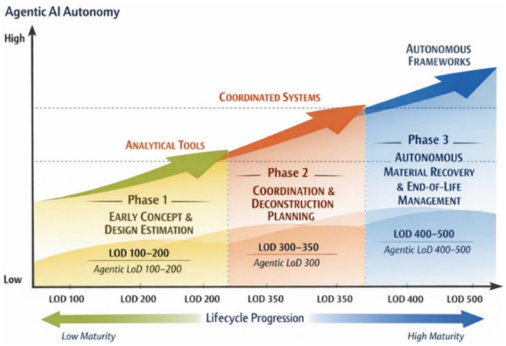

Fig. 1. BIM-AI maturity framework lifecycle diagram

Table 2. Six-dimensional agentic maturity rubric

Dimension	0	1	2	3
D1 Agency structure	No agent	Single analytical model	Coordinated workflow	Multi-agent, self-organizing agency
D2 Tool integration	No digital tool integration	Standalone model or software	BIM/DT, platform, robotics integration	Multi-tool, API, cloud integration
D3 Reasoning depth	Descriptive, review-level	Classification estimation	Rule-based planning, optimization	Iterative autonomous reasoning
D4 Adaptivity	Static, conceptual	Fixed data-driven model	Optimisation, scenario-responsive	Real-time feedback-driven adaptation
D5 Autonomy	No autonomous capability	Human in decision support	Automated workflow or execution	Autonomous, self-managed execution
D6 Environmental data resolution	Generic, conceptual	Document, survey, and generic data	BIM, material, building-level data	Sensor, reality-capture, robotic, DT, as-built data

3 Results and Discussion

3.1 Pairwise Domain Relationship Mapping Results

In the pairwise domain mapping analysis, the strongest relationship observed in the literature was between circular construction and AI-enabled BIM/DT infrastructures**.** Within this subset, studies demonstrated that digital material passports and lifecycle data platforms can support circular decision-making throughout the building lifecycle, particularly for reuse planning strategies [11, 19]. Contributions highlighted the integration of BIM with advanced digital technologies such as blockchain, IoT, and AI-supported analytics to improve transparency and traceability in supply chains [12, 14, 17]. Most contributions have remained focused on information structuring, assessment, and decision support rather than autonomous execution.

The second relationship concerned the integration of agentic AI systems within digital construction environments. Most studies fell into digital lifecycle infrastructure, focusing on broader construction automation problems. This confirms the central gap addressed by the proposed framework: while agentic AI research has advanced automation capabilities, the two trajectories have not yet been systematically integrated.

3.2 Agentic Maturity Assessment Results

The technological maturity of the identified systems was evaluated using the six-dimensional agentic maturity *rubric* presented in Table 2. The complete study-level coding matrix for all 37 analyzed publications is presented in Table 3. Accordingly, among the 37 analyzed publications, 11 studies were classified as having no agentic capability, corresponding to 29.7% of the corpus, while 10 studies were classified as analytical decision-support systems, representing 27.0%. The largest group consisted of 13 studies classified as coordinated computational workflows, corresponding to 35.1%. Only three studies, 8.1% of the corpus, reached the level of advanced agentic autonomy.

Table 3. Maturity level results of Agentic AI use through the analyzed publications

Ref.	D1	D2	D3	D4	D5	D6	Mean Score	Maturity Level	Agentic LoD (AloD) Category
[36]	1	1	2	1	1	1	1,17	1	ALoD 100–200
[37]	1	1	2	1	1	2	1,33	1	ALoD 100–200
[38]	1	1	1	1	0	3	1,17	1	ALoD 100–200
[39]	2	2	1	1	2	3	1,83	2	ALoD 300
[40]	1	1	1	1	1	2	1,17	1	ALoD 100–200
[41]	1	2	2	2	1	2	1,67	2	ALoD 300
[42]	2	3	2	2	2	3	2,33	3	ALoD 400–500
[43]	1	1	2	1	1	2	1,33	1	ALoD 100–200
[44]	1	2	1	1	2	2	1,50	2	ALoD 300
[45]	2	3	2	2	3	3	2,50	3	ALoD 400–500
[46]	2	2	1	1	2	2	1,67	2	ALoD 300
[47]	0	1	1	0	0	1	0,50	0	Below ALoD
[11]	0	1	1	0	0	1	0,50	0	Below ALoD
[12]	0	1	0	0	0	1	0,33	0	Below ALoD
[13]	0	1	1	0	0	1	0,50	0	Below ALoD
[14]	1	2	2	1	1	2	1,50	2	ALoD 300
[15]	0	1	1	0	0	1	0,50	0	Below ALoD
[16]	1	2	2	2	1	2	1,67	2	ALoD 300
[17]	1	2	1	1	1	2	1,33	1	ALoD 100–200
[18]	0	1	1	0	0	1	0,50	0	Below ALoD
[19]	1	1	1	1	0	1	0,83	1	ALoD 100–200
[20]	0	1	1	0	0	1	0,50	0	Below ALoD
[21]	1	2	2	2	1	2	1,67	2	ALoD 300
[22]	0	1	1	0	0	1	0,50	0	Below ALoD
[23]	0	1	1	0	0	1	0,50	0	Below ALoD
[24]	1	2	2	1	1	2	1,50	2	ALoD 300
[25]	1	2	1	1	1	2	1,33	1	ALoD 100–200
[26]	0	1	1	0	0	1	0,50	0	Below ALoD
[27]	1	2	1	1	1	2	1,33	1	ALoD 100–200
[28]	1	3	2	1	1	2	1,67	2	ALoD 300
[29]	2	3	2	1	2	2	2,00	2	ALoD 300
[30]	1	2	2	2	1	2	1,67	2	ALoD 300
[31]	1	2	1	1	1	2	1,33	1	ALoD 100–200
[32]	0	1	1	0	0	1	0,50	0	Below ALoD
[33]	1	2	2	1	1	2	1,50	2	ALoD 300
[34]	1	2	2	1	1	2	1,50	2	ALoD 300
[35]	2	3	2	2	2	3	2,33	3	ALoD 400–500

4 Conclusion

The fundamental technological components for circular construction are largely available in terms of BIM and DTs, providing structured data infrastructure, and agentic AI, providing task decomposition and autonomous decision-making logic. This study offers three key contributions. First, it systematically reveals the relationships among circular construction, BIM, DT infrastructure, and agentic AI through binary domain mapping. Second, it examines the current level of agentic AI development using a multidimensional evaluation rubric encompassing agent structure, tool integration, reasoning depth, adaptivity, autonomy, and environmental data resolution. Third, it demonstrates that

circular construction workflows require different levels of AI support across lifecycle phases, each corresponding to increasing levels of BIM data reliability and AI autonomy.

The pairwise domain results revealed that an integrated approach to supporting circular lifecycle processes remains limited due to a lack of conceptual alignment between AI autonomy and BIM data reliability. Most agentic AI implementations are currently applied to operational construction processes rather than lifecycle-oriented decision-making, and increasing levels of AI autonomy remain only indirectly connected to circular construction strategies. This highlights a structural gap between digitally enabled circular construction infrastructures and emerging agentic AI technologies.

This study is limited to a maturity assessment based on a review. Future research can extend the framework through expert review, stakeholder-driven criteria mapping, and application within operational circular construction workflows.

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