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Exploring the Different Dimensions of Building using Building Information Modelling

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ABSTRACT :

This research offers an integrated framework bringing together 4D, 5D, and 6D Building Information Modelling (BIM) strategies to improve lifecycle management, safety, cost, time, and sustainability in construction projects. Employing case studies like Donggou Bridge and a 3000 m² building, the research illustrates the real-world application of enhanced BIM technologies on different kinds of projects. The 4D BIM element, via the SCI4D system, brings generative planning to camera placement for optimized surveillance, improving on-site safety monitoring and threat detection. The 5D BIM implementation combines 3D design with scheduling and cost estimation via tools such as Autodesk Revit, Microsoft Project, and Navisworks, with increased planning precision, reduced waste, and real-time project control support. The 6D BIM extension includes carbon footprint analysis, which finds that embodied emissions are dominated by raw materials. Such early-stage adoption encourages stakeholder coordination and ensures sustainable, cost-effective, and timely delivery of the project. The integrated BIM framework enables improved decision-making, minimizes errors, and maximizes asset performance across the project's entire lifecycle. In total, this multidisciplinary framework develops a digital platform for more intelligent, safer, and more sustainable construction management.

INTRODUCTION

The international construction sector is currently experiencing a rapid transformation into a digital arena fueled by the increasing demand for sustainability, efficiency, and safety throughout the entire stage of infrastructure development. Conventional 2D-based design and documentation practices are progressively being substituted with state-of-the-art Building Information Modelling (BIM) technologies that facilitate integrated, data-enriched project environments. Of the various multidimensional extensions of BIM, 4D, 5D, and 6D models have become essential tools for the improvement of visualization, coordination, and decision-making in intricate construction projects.

Bridge and building infrastructures, which are the backbone of economic development, are frequently plagued with cost overruns, time slippages, and environmental inefficiencies as a result of fragmented design and management systems. The 6D BIM approach solves these problems by factoring in sustainability and lifecycle cost estimation parameters so that stakeholders are able to assess material impacts, energy usage, and carbon emissions from initial design phases. One good example is China's Donggou Bridge project, where 6D BIM integration showed drastic enhancements in lifecycle prediction and collaborative planning.

At the same time, the 5D BIM model also helps in the management of projects by interfacing 3D design components with time and cost information. Integration provides real-time visualization of the construction process, precise cost calculation, and proactive financial management, especially in the field of residential construction works. With the help of software tools like Autodesk Revit, Navisworks, and Microsoft Project, 5D BIM enables engineers and project managers to simulate different construction conditions, detect potential conflicts, and optimize

Safety continues to be a critical component of contemporary construction, complementing cost and sustainability objectives. By integrating 4D BIM and generative design software, like the SCI4D framework, intelligent and automatic planning of safety observation systems is achieved for real-time observation and hazard avoidance. Concurrently, the 4D, 5D, and 6D dimensions of BIM—time, cost, safety, and sustainability—constitute an integrated digital environment which bolsters project efficiency, reduces environmental footprint, and advocates safer, greener construction methods across infrastructure and building project lifecycles.

LITERATURE REVIEW

The international construction sector is currently experiencing a rapid transformation into a digital arena fueled by the increasing demand for sustainability, efficiency, and safety throughout the entire stage of infrastructure development. Conventional 2D-based design and documentation practices are progressively being substituted with state-of-the-art Building Information Modelling (BIM) technologies that facilitate integrated, data-enriched project environments. Of the various multidimensional extensions of BIM, 4D, 5D, and 6D models have become essential tools for the improvement of visualization, coordination, and decision-making in intricate construction projects.

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METHODOLOGY

This research combines 4D (schedule and safety), **5D (cost control), and **6D (sustainability) BIM dimensions to develop a holistic digital lifecycle management framework. Utilizing *Autodesk Revit, Navisworks, Microsoft Project, and Dynamo, the method provides **impeccable data interoperability throughout design, construction, and operation stages.

The methodology involves six steps:

1. Data acquisition
2. 3D model creation
3. Time–cost integration
4. Safety simulation
5. Sustainability analysis
6. Validation

Step 1: Data Collection and Model Preparation

- Input Data: Architectural, structural, and MEP drawings; project schedules; cost breakdowns; and sustainability data (material quantities, embodied carbon coefficients, and energy consumption factors).
- Software Utilized: Autodesk Revit 2023 for the generation of 3D models and Microsoft Excel for managing input data.
- An A Level of Development (LOD 300) model having geometric and non-geometric data for every component.

Step 2: 4D BIM – Time and Safety Integration

- 4D BIM – Safety and Time Integration
- The 3D Revit model is imported with a construction schedule in Navisworks Manage to create a 4D simulation.
- By applying SCI4D principles, a parametric safety monitoring model is created in Dynamo, with automated surveillance camera placement based on dynamic site layouts.
- This step allows for visualizing the sequence of construction and identifying possible safety conflicts.

Step 3: 5D BIM – Cost Simulation and Resource Optimization

- 5D BIM – Cost Simulation and Resource Optimization
- The 4D model is extended to incorporate cost factors like material, labor, equipment, and upkeep costs.
- Microsoft Project is integrated with Navisworks Quantification to obtain reliable cost estimates and monitor cash flow.
- This enables real-time comparison between expenditures planned and actual, assisting in reducing budget deviations.

Step 4: 6D BIM – Sustainability and Lifecycle Assessment

- 6D BIM – Sustainability and Lifecycle Analysis
- From data supplied by the 5D model, carbon footprint and energy consumption are determined using standard factors of emissions (e.g., UK BEIS 2018).
- The lifecycle analysis (LCA) analyzes the environmental performance at material extraction, transportation, construction, operation, and demolition phases.
- Sustainability indicators like embodied CO_2, energy intensity, and material recyclability are measured

Step 5: Integration and Analysis

- The 4D–6D BIM datasets are integrated within one integrated Revit–Navisworks–Dynamo environment with uninhibited data flow across safety, cost, and sustainability modules.
- Real-time dashboards represent performance indicators like project progress, cost fluctuation, safety compliance, and carbon emissions.
- Multi-criteria analysis is carried out to maximize cost, time, and sustainability objectives.

Step 6: Validation and Optimization

- The integrated model is validated through case studies: Donggou Bridge (for validation of sustainability), a residential building (cost/time analysis), and a 3000 m^2 safety monitoring site (4D safety validation).
- Simulation outputs are compared to baseline performance measures from conventional methods.
- Optimization is centered on minimal carbon impact, utmost safety cover, and less project delay.

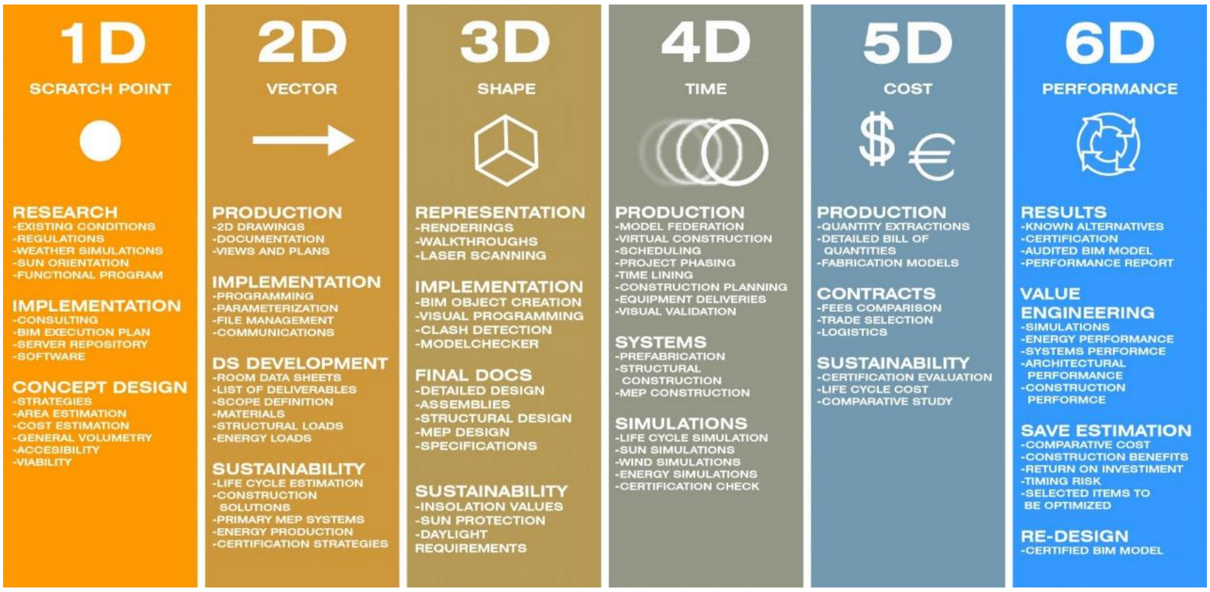

Fig: Evolution of Building Information Modelling (BIM) Dimensions from 1D to 6D

Sl. No	Aspect	Applications	Challenges	Future Advancements
1	Materials	Self-assembling tructures Adaptive facades Smart construction naterials Shape-memory omponents Programmable netamaterials	Limited printable naterials Material durability and tability Cost constraints	Development of dvanced materials Biodegradable and ustainable options Integration of anotechnology for nhanced properties
2	Design & Modeling	Complex geometric tructures Customizable omponents Responsive designs Programmable & econfigurable designs Bio-inspired rchitectures	Software limitations Design complexity Integration challenges	Enhanced design oftware AI-driven design ptimization Bioinformatics for bio-nspired solutions
3	Construction	Self-assembling nfrastructure On-site assembly utomation Rapid prototyping Disaster-responsive tructures Customizable onstruction	Limited construction echniques Skill training gaps Integration hurdle	Specialized construction echniques Robotics for automation Standardized onstruction protocols On-demand 4D printing ervice
4	Sustainability	Reduced material waste Energy-efficient tructures Reconfigurable buildings Pollution-absorbing tructures Water-responsive rchitecture	Environmental impact Energy consumption Recycling challenges	Eco-friendly 4D printing naterials Energy-efficient printing echniques Water-based & biodegradable solutions-Recycling innovations
5	Cost & Time	Faster construction imelines Reduced labor cost Minimized errors-	Initial technology nvestment R&D costs Time-consuming	Economical 4D printing echnologies Cost-effective materials & supply chain

		ustomizable & on- lemand construction Streamlined supply hai	processes	Management Faster R&D cycles On-demand printing service
6	unctionality	Responsive structures Programmable omponents Real-time esponsiveness Wearable & bio- ntegrated architecture Interactive installation	Limited long-term tability understanding- Precision challenges Sensor integration	Long-term stability tudies- Enhanced precision & accuracy IoT integration for real- ime monitoring Bio-sensing technologie
7	Regulatory	Customizable & ompliant structures Disaster-resistant lesigns Heritage preservation Urban planning olution	Lack of standardized egulations Safety certifications Legal concerns	Collaboration for tandard guidelines Safety certifications for naterials Legal frameworks for iability issues Integration of 4D printing n urban planning policies

Table 1: Applications, challenges, and future advancements of 4D Printing in AEC Industry

CONCLUSION

This research proves that the incorporation of several BIM dimensions—4D, 5D, and 6D—builds an integrated system for enhancing construction project safety, efficiency, and sustainability in their entire lifecycle. The 6D BIM model improves environmental performance through the inclusion of carbon footprint analysis and lifecycle assessment so that more reasoned material choices and sustainable design decisions are possible, as in bridge infrastructure projects such as the Donggou Bridge. The 5D BIM solution successfully integrates cost and time parameters with 3D models to facilitate accurate budgeting, scheduling, and resource allocation in residential construction projects. In contrast, the 4D BIM solution, facilitated by generative design software like SCI4D, offers a novel solution for safety management by automating surveillance planning and enabling real-time visualization of risk. Together, these dimensions create a data-driven environment in which cost effectiveness, safety guarantee, and environmental stewardship coexist. The use of 4D–6D BIM not only increases the coordination between project parties but also fosters transparency, minimizes rework, and avoids uncertainties about the project. Generally, the multi-dimensional BIM approach is a revolutionary step towards smart, sustainable, and resilient building practices, facilitating global movement towards digitalization and lifecycle infrastructure management

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