Table S1. List of reviewed articles (BIM- LCA integration)

Reference	Title	Year	Country	BIM Model		LCA Method								Software Integration			Results Communication	
									LCA phases									
				Building Typology	LOD	Functional Unit	Life Span	LCI Database	Product A1-A3	Construction A4-A5	Use B1-B7	End of Life C1-C4	Recycling D	BIM tool	Data Exchange Procedure	LCA tool	Environmental Impact indicators	Key point
[1]	BIM-integrated LCA to automate embodied carbon assessment of prefabricated buildings	2022	China	typical prefabricated high-rise buildings	–	Complete building	–	Obtained from the BIM model	3	3	7	7	7	Autodesk Revit	BIM → ifc file →Excel → SimaPro	SimaPro	Embodied carbon	Automation of the embodied carbon assessment of prefabricated buildings at five levels: material, component, assembly, flat, and building
[2]	BIM-based life cycle assessment for different structural system scenarios of a residential building	2022	Egypt	residential building	400	one square metre of the usable floor area (UFA)	50 years	Ecoinvent	A1, A3	3	B6, B7	3	3	Autodesk Revit	From BIM (BoQs) to OneClickLCA → Synchro pro	OneClickLCA	GWP, AP, EP, ODP, POCP, PED	Comparison of 3 different structural scenarios
[3]	Development of Building Information Modeling Template for Environmental Impact Assessment	2021	Korea	18 storey apartment building	300	Complete building	40 years	Korean LCI database	3	7	B1 B2	7	7	Autodesk Revit	Including life cycle environmental impact into BIM models (LCA results presented in Excel)	–	GWP, ADP, AP, EP, ODP, POCP	Developing BIM-LCA integration approach
[4]	Life Cycle Assessment Framework for Embodied Environmental Impacts of Building Construction Systems	2021	Egypt	2 storey university student center	–	Complete building	50 years	EPD	3	3	3	3	3	Bentley	From BIM (BoQs) to Excel sheet	–	Non-renewable primary energy, GWP	comparison of a life cycle assessment framework for embodied environmental impacts of three building types

[5]	Building information modelling application of material, water, and climate footprint analysis	2021	Germany	3 storey multi-family building	–	one square metre of the usable floor area (UFA)	–	GaBi	3	7	7	7	7	Autodesk Revit	Linking BIM materials' information with LCA data by using a developed application	openLCA	GWP	Comparison of three LCA methods
[6]	An integrated approach of BIM-enabled LCA and energy simulation: The optimized solution towards sustainable development	2021	Australia	one-story brick veneered house	–	Complete building	60 years	In-house database in Tally	3	3	3	3	3	Autodesk Revit	Revit → Tally	Tally	GWP, AP, RED, EP, ODP, SFP,NRED, PED	Sensitivity analysis
[7]	Life cycle environmental impact assessment to manage and optimize construction waste using Building Information Modeling (BIM)	2021	Canada	12 storey commercial building	–	Complete building	75 years	ATHENA Impact Estimator	7	3	3	3	7	Autodesk Revit, Navisworks, Tekla	From BIM to external database	Athena IE LCID	GWP, AP, HH, EP, ODP, SMP	Comparison of a the conventional method and some rules of DfD approach
[8]	The BIM-Based multi-optimization approach in order to determine the trade-off between embodied and operation energy focused on renewable energy use	2021	Iran	8-story residential building	–	exterior shell materials	60 years	In-house database in LCA tool	3	3	3	3	3	Autodesk Revit, Rhino software	From BIM (BoQs) to Athena From Rhino to EnergyPlus	Athena IE LCID	Renewable energy use, embodied energy, operational energy, total energy	Parametric Simulation

[9]	Integrated BIM-Based LCA for the Entire Building Process Using an Existing Structure for Cost Estimation in the Swiss Context	2020	Switzerland	mixed-use timber building	LOD 100-LOD 400	one square metre of the usable floor area (UFA)	–	KBOB/Bauteilkatalog	3	7	B4	C3, C4	7	Autodesk Revit, Dynamo	From BIM (BoQs) to Dynamo LCA database → Dynamo	–	Grey energy, CO2eq	Comparison of environmental impacts in different LODs
[10]	Comparative BIM-based Life Cycle Assessment of Uruguayan timber and concrete-masonry single-family houses in design stage	2020	Uruguay	Two single-family houses	300	one square metre of heating area	60 years	Ecoinvent Version 2.0	3	3	B2, B3, B4, B6	C1, C2, C4	7	ArchiCAD 19	From BIM (BoQs) to Excel Multiplying BOQ with environmental impact factors	–	GWP, AP, EP, FWE, HT, ODP	Comparison of two design options
[11]	An integrated life cycle assessment of different façade systems for a typical residential building in Ghana	2020	Ghana	Single storey building	–	180.50 m2 GFA	50 years	ICE database	3	3	B6	7	7	Autodesk Revit	From BIM (BoQs) to EXCEL (carbon coefficient/ energy coefficient) (embodied) BIM →gbxml → IES-VE (operational energy → energy/carbon conversion factor → operational GWP)	–	GWP, cumulative energy demand	Comparison of LCA and LCC between four different facade systems
[12]	A BIM-LCA approach for estimating the greenhouse gas emissions of large-scale public buildings: A case study	2020	China	Guangdong Inkstone Culture Museum	–	one square metre of the gross floor area (GFA)	50 years	Literature	3	3	3	3	7	Autodesk Revit	BOQ and carbon factor→Excel BIM →gbXML →Designbuilder	–	Co2 emissions	Comparison of CO2 emissions over the life cycle, sensitivity analysis
[13]	Evaluation of BIM-based LCA results for building design	2020	Switzerland	three storey extension of an office building	–	Complete building	–	KBOB	3	7	7	C3, C4	7	Autodesk Revit, Dynamo	BIM→ BOQ (with KBOB ID) → Dynamo LCA factors → Excel → Dynamo	–	GWP	Identifying hotspots of environmental impacts

[14]	Detailed Assessment of Embodied Carbon of HVAC Systems for a New Office Building Based on BIM	2020	Switzerland	Seven storey an office building	300	Complete building	60 years	KBOB, Ecoinvent	3	7	B4 B6	C1, C2, C3	7	Autodesk Revit, Dynamo	From BIM (BoQs) to Dynamo LCA database to Dynamo to Excel	–	GWP	Comparison design alternatives
[15]	Assessing the sustainability of alternative structural solutions of a building: A case study	2020	Lithuania	Structural model of a residential building	–	Complete building	–	In-house database in Simapro	3	7	7	7	7	Tekla	From BIM (BoQs) to SimaPro	SimaPro	Primary energy demand, GWP, ODP	Comparison between three structural design alternatives
[16]	Development of a BIM-based Environmental and Economic Life Cycle Assessment tool	2020	Morocco	250-m high tower	200	Complete building	50 years	CYPE, Ecoinvent	3	3	3	3	7	Autodesk Revit	BIM model → Including LCA data into BIM objects	BIMEELCA	ADP, AP, EP, GWP, ODP. POCP, prE, nRE	Validating the applicability of developed BIM-LCA integration approach
[17]	BIM-based life cycle assessment and life cycle costing of an office building in Western Europe	2020	Netherlands	office building under construction	–	Complete building	50 years	IBU, OKOBAUDAT, MRPI, Ecoinvent, EPD	7	3	3	3	7	Autodesk Revit	From BIM (BoQs) to LCA data → Excel → BIM objects	BIMEELCA	AP, ADP, POCP, ODP, prE, nRE	Automatic simulations during the design and operation phase
[18]	Reduction strategies for greenhouse gas emissions from high-speed railway station buildings in a cold climate zone of China	2020	China	high-speed railway station (HSRS) building	–	1 m2 of unit gross floor area (GFA)	50 years	Literature (the Chinese national standard for building carbon emission calculation)	3	7	B4 B6	7	7	Autodesk Revit	BIM model →BOQ/Quota calculation method (the quantities of unclear materials, such as the steel bars in concrete structure) → Excel-based LCA tool BIM model → EnergyPlus	Excel based LCA tool	GHG emissions	Sensitivity analysis of multiple design variables of building envelop

[19])	Modular approach to multi-objective environmental optimization of buildings	2020	Hungary	residential building	–	Complete building	50 years	Ecoinvent database with certain modification	3	3	B2-B4 B6	C2-C4	7	Rhinoceros	Honeybee (model)→LCA (python) Honeybee →EnergyPlus	Ladybug&Honeybee plug-in for Grasshopper with custom extensions to include the LCA data	GWP, ODP, AP, POCP, EP, and cumulative energy demand	Parametric design
[20]	BIM-based life cycle environmental performance assessment of single-family houses: Renovation and reconstruction strategies for aging building stock in British Columbia	2020	Canada	single-family house	–	Complete building	50 years	Ecoinvent in SimaPro	3	3	3	3	7	Autodesk Revit	From BIM (BoQs) to SimaPro BIM →HOT 2000	Athena IE LCID	GHG emissions	Comparison of six design scenarios
[21]	Integration of BIM and Energy Consumption Modelling for Manufacturing Prefabricated Components: A Case Study in China	2019	China	Middle School	–	Complete building	40 years	literature	3	3	7	7	7	Autodesk Revit	Including energy consumption inventory in BIM objects, Extracting material information from the BIM model → Excel → calculating energy consumption in Excel	Excel based LCA tool	Energy consumption	Comparison of energy consumption between different materials during different stages
[22]	Development of a carbon emissions analysis framework using building information modeling and life cycle assessment for the construction of hospital projects	2019	China	a four storey building	–	–	50 years	Carbon factor from literature	3	3	3	3	3	Autodesk Revit	BIM → Glondon → BOQ → carbon factor BIM → GBS	spreadsheet, Glodon GTJ2018	CO2eq	Carbon emission analysis of materials, work types

[23]	Integrating building information modeling and life cycle assessment in the early and detailed building design stages	2019	Canada	four-storey multi-residential building	100, 300	Complete building	–	Ecoinvent Version 3.3	3	3	3	3	3	Autodesk Revit	Creating a database compiling all the different options for each assembly and all the corresponding LCI using Revit	Open LCA	Climate change, ecosystem quality, human health, resources	Comparison of two different LOD
[24]	Continuous BIM-based assessment of embodied environmental impacts throughout the design process	2019	Switzerland	multi-family house	100, 200, 300, 400	one square metre of heated floor area	60 years	Swiss Buildings Database, KBOB and Bauteilkatalog, based on Ecoinvent 3.3 background data s	3	7	B4	C3, C4	7	3D model in Rhinoceros	From 3D model to BOQ in Excel LCA database to Excel	–	GWP	Improving BIM-LCA integration approaches
[25]	Evaluation of BIM based LCA in early design phase (low LOD) of buildings	2019	Norway	commercial building	200, 300, 350	m3 for building materials	–	EPD	3	7	7	7	7	Autodesk Revit	BIM model →BOQ →Excel →One Click LCA	OneClick LCA	GWP	Comparison of four alternatives with different LODs
[26]	Integrated optimization with building information modeling and life cycle assessment for generating energy efficient buildings	2019	Brazil	a multi-story residential building	–	Complete building	–	GaBi	3	3	B6	7	7	Autodesk Revit	From BIM to Open Tally/GBS	Tally	Energy, AP, EP, GWP, ODP, SP, PED, PE-Re, PE-NRe	Simulation of alternative construction components
[27]	Life cycle assessment methodology integrated with BIM as a decision-making tool at early-stages of building design	2019	Brazil	multi-story office building	–	Complete building	–	Ecoinvent Version 3	3	3	3	3	7	Autodesk Revit	From BIM to Open LCA/GBS	Open LCA	Human health, ecosystem quality, resource depletion	Comparison of two construction methods

[28]	Simulation-Based Multi-Objective Optimization of Institutional Building Renovation Considering Energy Consumption, Life-Cycle Cost and Life-Cycle Assessment	2019	Canada	Two-storey office building	300	Complete building	–	ICE database	3	A5	3	C1, C3, C4	7	Autodesk Revit	Database link to BIM	Athena IE LCID	GWP, EE, OE	
[29]	How to design buildings with Life Cycle Assessment by accounting for the material flows in refurbishment	2019	Finland	four-storey building	–	one square metre of heated floor area	60 years	EPD, in-house database in One Click LCA	3	7	B4 B5	3	7	–	From BIM (BoQs) to OneClickLCA	OneClickLCA	GWP	Comparison between three scenarios
[30]	Comparative Whole-Building Life Cycle Assessment of Renovation and New Construction	2019	US	2-story, 5,500 m2, stand-alone building	–	Complete building	–	GaBi	3	A4	3	C2, C3, C4	3	Autodesk Revit	From BIM to Excel sheet	Tally	AP, EP, GWP, ODP, SMP, NRED	
[31]	Development of an Approach to Assess the Life Cycle Environmental Impacts and Costs of General Hospitals through the Analysis of a Belgian Case	2019	Belgium	7 storey hospital	–	Complete building	–	Ecoinvent 2.2	3	3	B2, B4, B5, B6, B7	C1, C2, C3	7	Autodesk Revit	From BIM to Excel sheet	SimaPro version 8.3	GWP, PE, AP, HTP, PM	
[32]	An integrated BIM-based framework for the optimization of the trade-off between embodied and	2018	Sweden	A semi-detached low-energy dwelling	–	one square metre of the usable floor area (UFA)	50 years	Primary energy factor from literature	3	7	B1, B4, B6, B7	7	7	Autodesk Revit, Dynamo, Slingshot	From BIM to Dynamo → gbXML → Grasshopper (Archsim)	–	Embodied energy, operational energy	Parametric design

	operational energy																	
[33]	LCA and BIM: Visualization of environmental potentials in building construction at early design stages	2018	Austria	residential building	200	Complete building	–	Ecoinvent	–	–	–	–	–	Autodesk Revit, Dynamo	From BIM (BoQs) to geometric and physical characteristics (Dynamo)	–	GWP	Comparing a wide variety of possible construction
[34]	A BIM based tool for assessing embodied energy for buildings	2018	China	a cast-in-situ concrete frame structure	–	Complete building	–	ICE database	3	3	7	7	7	Autodesk Revit	BIM→ developed plugin ICE database and other databases → developed plugin	developed plugin	GWP	Validating the developed BIM-LCA integration approach
[35]	Building-information-modeling enabled life cycle assessment, a case study on carbon footprint accounting for a residential building in China	2018	China	Village building	300	1 m2 of unit gross floor area (GFA)	50 years	CLCD, Ecoinvent,ELCD	3	3	3	3	7	Autodesk Revit	From BIM (Glondon BIM 5D) BOQs to Excel to eBalance From BIM to gbXML → Designbuilder	–	GWP	Hotpot identification
[36]	BIM-Based LCA Method to Analyze Envelope Alternatives of Single-Family Houses: Case Study in Uruguay	2018	Uruguay	single-family house	300	2 m2 of unit gross floor area (GFA)	60 years	Ecoinvent	3	3	B2, B4, B6	C1, C2, C4	7	Graphisoft Archicad	From BIM (BoQs) to Excel sheet	Excel based LCA tool	GWP, ODP, Freshwater aquatic ecotoxicity, human toxicity	Comparison of three design scenarios of envelopes
[37]	Comparative analysis between a complete LCA study and results from a	2018	Brazil	five typologies of wall systems	–	1 m2 of the nonstructural shell	–	Ecoinvent	7	7	7	7	7	Autodesk Revit, Autodesk Dynamo	From BIM to Gabi/Tally	Tally, Gabi	AP, EP, GWP, ODP, SP, nRE, prE	Comparison of different walls

	BIM-LCA plug-in																	
[38]	Life cycle assessment and environmental-based choices at the early design stages: an application using building information modelling	2018	Brazil	–	–	Wall and Roofing system	–	Ecoinvent	7	7	7	7	7	Autodesk Revit, Autodesk Dynamo	Including LCA data into BIM objects	Excel based LCA tool	GWP, AP, EP, ODP, SP, nRE, prE	Comparison of different material specification
[39]	BIM-embedded life cycle carbon assessment of RC buildings using optimised structural design alternatives	2018	UK	10-storey residential development	–	1 m2 of unit gross floor area (GFA)	–	EPD, literature	3	7	7	7	7	Autodesk Revit	From BIM (BoQs) to BIM schedules EPD → BIM schedule	Excel based LCA tool	Embodied CO2eq	Parametric design
[40]	A BIM–LCA integration technique to embodied carbon estimation applied on wall systems in Brazil	2018	Brazil	–	–	–	–	Ecoinvent	3	7	7	7	7	ArchiCAD	SimaPro → carbon footprint → ArchiCAD → Excel	SimaPro	CO2eq	Comparison of two different construction methods
[41]	Building information modeling-based model for calculating direct and indirect emissions in construction projects	2017	Saudi Arabia	3 storey building	–	Complete building	50 years	Athena IE LCID	3	3	3	3	7	Autodesk Revit	BIM model to Access to Athena impact estimator	Athena IE LCID	GWP, AP, EP, ODP, SP	Hotpot identification

[42]	Integration of BIM and LCA: Evaluating the environmental impacts of building materials at an early stage of designing a typical office building	2017	Brazil	multi-story office building	–	Complete building	50 years	GaBi	3	7	3	3	7	Autodesk Revit	BIM → Tally/GBS	–	AP, EP, GWP, ODP, SP, prE, nRE, energy consumption	Hotpot identification
[43]	A benchmark study of BIM-based whole-building life-cycle assessment tools and processes	2017	US	simple unit space	–	Wall	60 years	In-house database in Tally and Athena Impact Estimator	7	7	7	7	7	Autodesk Revit	BIM →Tally BIM →BOQ → Athena Impact Estimator	Tally Athena IE	ODP, GWP, AP, SP, prE, nRE	Sensitivity analysis
[44]	An integrated BIM-based framework for minimizing embodied energy during building design	2016	Sweden	semi-detached dwelling	–	Complete building	50 years	EPD inventory	3	A4	7	7	7	Autodesk Revit	From BIM (BoQs) (extracted by ETL) to EPDs	–	nRE, CO2eq emissions	Comparison of nineteen wall scenarios
[45]	BIM in LCA / LCEA Analysis : Comparative analysis of Multi-family House and Single-family	2016	Portugal	multi-family house vs single-family house	–	Complete building	60 years	GaBi	3	3	3	3	3	Autodesk Revit	From BIM to Tally	Tally	AP, EP, GWP, ODP, SP, nRE, prE	Comparison between single-family and multi-family house
[46]	Calculation of a building's life cycle carbon emissions based on Ecotect and building information modeling	2016	China	Run Run Shaw Architectural building	–	Complete building	–	Emission factor in China	3	3	3	3	7	Autodesk Revit	From BIM (BoQs) to Excel sheet	–	Energy consumption, carbon emission	Sensitivity analysis
[47]	Life cycle environmental performance of material specification: a BIM-enhanced	2015	US	Two-storey primary schoolbuilding	200	Complete building	30 years	ATHENA Impact Estimator	3	3	3	3	7	Autodesk Revit	BIM (IFC) → ATHENA Impact Estimator BIM → Green Building Studio (GBS) →	Athena IE LCID	GWP, HH	Hotpot identification, comparison of five design scenarios

	comparative assessment													ATHENA Impact Estimator				
[48]	Green Template for Life Cycle Assessment of Buildings Based on Building Information Modeling: Focus on Embodied Environmental Impact	2015	Korea	A standard 18 storey Korean apartment building	300	Complete building	–	Korea life-cycle inventory database	3	3	3	3	7	Autodesk Revit	Including embodied environmental impact evaluation results into BIM objects	–	ADP; AP; EP; GWP; ODP;POCP	Parametric modelling
[49]	Carbon footprint assessment of a typical low rise office building in Malaysia using building information modelling (BIM)	2015	Malasia	Two-storey office building	–	Complete building	–	ICE database	3	3	7	7	7	Autodesk Revit	From BIM to Excel sheet	–	Carbon footprint	Comparison of six structural models
[50]	BIM Application to Select Appropriate Design Alternative with Consideration of LCA and LCCA	2015	Korea	11-storey office building	–	Complete building	–	Korea life-cycle inventory	3	7	B1-B6	7	7	ArchiCAD 15	From BIM (BoQs) to Excel LCA data → Excel Calculation LCA in Excel	–	Carbon emissions	Comparison of three different external skin systems
[51]	Life cycle emissions analysis of two nZEB concepts	2015	Norway	Typical two-storey single-family house and office building	–	one square metre of heated floor area	60 years	Ecoinvent Version 2.2	3	7	B1 B4 B6	7	7	Autodesk Revit	From BIM to Excel sheet	SimaPro version 7.3	ECOE, OCOE	
[52]	A net zero emission concept analysis of a single-family house	2014	Norway	Single-family house	–	one square metre of heated floor area	30 years Solar panels	Ecoinvent Version 2.2	3	7	B4 B6	7	7	Autodesk Revit	From BIM to Excel sheet	SimaPro version 7.3	CO_2eq, annual energy demand	Sensitivity analysis

[53]	An Automated BIM Model to Conceptually Design, Analyze, Simulate, and Assess Sustainable Building Projects	2014	Canada	Three-storey office building	–	Complete building	–	ATHENA Impact Estimator	3	7	B6	7	7	Autodesk Revit	From BIM trough ODBC exporting format	Athena IE LCID	AP; EP; GWP; HH; ODP; PEC; PCSP; REP; WRRU	
[54]	Application of life-cycle assessment to early stage building design for reduced embodied environmental impacts	2013	US	Residential building	–	Complete building	–	In-house database in SimaPro and Athena EcoCalculator	3	7	3	7	7	DProfiler	From BIM (BoQs) with UniFormat 2010 classification system to Athena impact estimator/SimaPro	SimaPro, Athena Eco Calculator	CO2eq emissions	Sensitivity analysis
[55]	Embodied and operational energy for new-build housing: A case study of construction methods in the UK	2013	UK	Single-family house	–	Complete building	60 years	ICE database	3	7	B6	7	7	–	From BIM to Excel sheet	–	ECOE, OCOE	
[56]	Integrating building information modelling with sustainability to design building projects at the conceptual stage	2013	Canada	Six-storey apartment building	–	Complete building	–	Athena Impact estimator, EPD	3	7	3	7	7	Autodesk Revit	From BIM to external database	Athena IE LCID	Fossil fuel, ODP, SP, GWP, AP, human health respiratory effects	Developing BIM-LCA integration approach

Table S2. List of reviewed papers (BIM- LCC integration)

Reference	Year	Country	Title	BIM Tool	LCC Analysis Tool	Data Management Tool
[57]	2015	South Korea	BIM application to select appropriate design alternative with consideration of LCA and LCCA	Archicad	EcoDesigner software, Excel worksheet-based framework	Microsoft Excel
[58]	2015	Hong Kong	Building information modeling based building design optimization for sustainability	Autodesk Ecotect	Pareto-optimal front	Multi-Objective Particle Swarm Optimization (MOPSO)
[59]	2017	Ireland	Embedding life cycle costing in 5D BIM	Autodesk Revit	CostX 5D BIM software	Exactal CostX with 5D BIM platform
[60]	2017	Taiwan	BIM-based approach to simulate building adaptive performance and life cycle costs for an open building design	Autodesk Revit	NPV, The FDS+EVAC tool, CFD, The daylight analysis software	Microsoft Excel
[61]	2018	Egypt	BIM-based approach for optimizing life cycle costs of sustainable buildings	Autodesk Revit	Monte Carlo, Genetic Algorithm(GA)	Microsoft Excel
[62]	2019	Netherlands	BIM-based life cycle assessment and life cycle costing of an office building in Western Europe	Autodesk Revit, Tally, Athena	BIMEELCA tool	LCA database (GaBi), Microsoft Excel
[63]	2019	Denmark	Implementing life-cycle costing: Data integration between design models and cost calculations	Autodesk Revit	Sigma Estimates, 5D BIM cost software Dynamo model	Molio Price Database, MS Excel-based tool
[64]	2019	Portugal	BIM-based LCA assessment of seismic strengthening solutions for reinforced concrete precast industrial buildings	Autodesk Revit	Tally LCA Software	Tally database
[65]	2019	Canada	Simulation-based multi-objective optimization of institutional building renovation considering energy consumption, life-cycle cost and life-cycle assessment	Autodesk Revit	Simulation-Based Multi-Objective Optimization model	Take-Off (MTO) table
[66]	2020	Portugal	Integration of LCA and LCC analysis within a BIM-based environment	Autodesk Revit	BIM-LCA/LCC analysis	IfcDoc tool, IDM/MVD
[67]	2020	South Korea	BIM-based preliminary estimation method considering the life cycle cost for decision-making in the early design phase	Autodesk Revit	JAVA-based eclipe JSP, Web-based user interface (UI)	Oracle SQL Developer
[68]	2020	Morocco	Development of a BIM-based environmental and economic life cycle assessment tool	Autodesk Revit	BIMEELCA tool, Streamlined LCA/LCC analysis based	Microsoft Excel, Revit GUI
[69]	2020	Thailand	A BIM-integrated relational database management system for evaluating building life-cycle costs	Autodesk Revit	Relational database management system (RDBMS)	Microsoft Excel
[70]	2020	Ghana	An integrated life cycle assessment of different façade systems for a typical residential building in Ghana	Autodesk Revit	Integrated Environmental Solutions Virtual Environment (IES-VE)	Microsoft Excel

[71]	2021	Iran	BIM-based approach to conduct Life Cycle Cost Analysis of resilient buildings at the conceptual stage	Autodesk Revit	Green Building Studio (GBS), The developed BIM-LCCA plug-in	RSMeans cost database, Microsoft Excel, Microsoft Access, Platform Revit API
[72]	2021	China	A performance data integrated BIM framework for building life-cycle energy efficiency and environmental optimization design	Autodesk Revit	A performance integrated BIM (P-BIM), Ladybug Tools, EnergyPlus, Octopus tool	Platform Revit API, MySQL, Rhino
[73]	2023	Iran	Energy, economic and comfort optimization of building retrofits considering climate change: A simulation-based NSGA-III approach	DesignBuilder	Simulation-Based Multi-Objective Optimization model, GA	Microsoft Excel

Table S3. List of reviewed papers (BrIM)

Different life cycle stages of bridge engineering															
	Planning and Design				**Construction schedule**				**Operation and Maintenance**					**Information Exchange**		
BIM Practice	_Parametric analysis	_Parametric modeling, _parametric design,	_GHG Emission	_Integrated design _Simulation, _visualization	Construction schedule	Cost and budget estimate	Crane location	Dimension estimation	Bridge Management System (BMS)	Bridge monitoring and inspection	Bridge evaluation	Operation and maintenance cost	Maintenance scheduling	Interoperability	Data integration	IFC standard
References	[74]	[75–77]	[78]	[79–81]	[76,78,82–84]	[76,78,82,83, 85]	[86,87]	[88,89]	[90]	[79,91,92]	[93–95]	[96,97]	[98,99]	[79]	[98,100,101]	[18,102,103]

Outcome	_At the conceptual bridge design stage, the proposed BrIM system incorporates several bridge MR and R solutions into a multi-criteria decision making method (MCDM) to obtain competitive priority ratings. _ By exporting BrIM input databases in IFC file format, information loss is minimised.	_ Bridge models in three dimensions that took into account WBS and PBS-enabled digital mock-ups, design improvement, and accelerated construction engineers' learning. _ A virtual bridge assembly allowed for the identification of various faults in two-dimensional drawings. _ The knowledge of structural configuration is improved by 3D models and DMU, particularly for complex systems.	_ calculating the embodied carbon emissions of the raw materials and the carbon emissions produced by the machinery in the initial stages of the bridge lifecycle using 6D BIM methodologies,	_ Engineers may access and update model data for the bridge life cycle analysis and control, including minimising tolerances during the erection stage and some unanticipated damage/deterioration during operation, thanks to the master digital model.	_ 3D BrIM was used to cut the construction time and the productivity of the site's operation was increased; _ Utilizing BIM could help with difficult project scheduling and result in cost savings by reducing the need for change orders and rework; _ The value of the planned percentage completion (PPC) range increased by installation of piles at various locations within the limits of the site space ensured by 4D visualisation of the construction phase;	_ by integrating the BrIM model with 3D models, It makes it easier to conduct precise cost estimates and review estimates _ projected costs, and actual costs were all recorded using 4D BrIM. Earned value calculations were then made, and the budget and schedule status was ascertained	_ Importing the crane model and modelling the erection process might help choose the ideal crane position when utilising a 3D model. _ Planning for lifting operations and construction monitoring are streamlined through the use of BIM and unmanned aerial vehicles (UAVs).	_ 92.2% of the dimensions calculated using the suggested technique (automated production of as-built BIM of precast concrete panels using laser scan data) differed by less than 3 mm from the measurements determined by manual measurement. _a new framework that uses camera-based unmanned aerial systems (UASs) to gather and analyse inspection data, and BrIM to store and manage all associated inspection data	_ A balanced approach to decision-making is suggested for the management of bridge maintenance under various limitations, such as cost optimization and expert advice.	_ Using the created dynamic BIM viewer, key structural performance parameters may be dynamically shown. Significant cost savings could be achieved by reducing tactile and visual inspections and maintenance by implementing BIM features during an asset's operational period._Actual deformation curves more closely matched the deformation displacement curves obtained by the BIM monitoring system. _A chain of algorithms based on a computer vision was embedded into an AR device that aims to enhance the precision and performance of inspection tasks. After, the technical damage report is fed-back to the management system and is available for assessment and discussion.	_ The random spatiotemporal conflict detection approach can help decision-makers look into various demolition start dates by efficiently calculating the random conflict likelihood due to the change in reconstruction work time. _BrIM for inspection and evaluation method offers a way to gather, store, and use location-based damage data from a bridge inspection by using BIM software to analyse and present that data to help with decisions by allowing the user to evaluate damages based on location and offering maintenance recommendations	_Accurately predicted the operation and maintenance cost of target projects. _ Through the actual data, the effect of operation and maintenance management was verified and operation and maintenance cost was reduced. _A bridge data management system could significantly help engineers to save time and money on inspection and repairs.	_Maintenance engineers were able to perform their daily tasks in nearly 50% less time and with 20–40% higher accuracy.	_Addressed the existing collaboration gap among different stakeholders and the discontinuity of information between the various stages of bridge projects. Digital models need to be updated by adding more information on their performance.	_Four-dimensional modeling has the potential to provide an effective means of sustainable integration of various data categories with 3D models of an infrastructure over its lifetime. _Damaged data structure and semantics definitions proposed. _ It is possible to either apply the proposed approach to an external IFC file and simply link it with BMS or insert an IFC representation of every specific bridge into the BMS.	_Developed rules of unique identifier and information reassignment, and applied a semi-automated naming algorithm. _It was observed that information retrieval and extraction for components was possible through a semantic-based query to the generated IFC-based bridge information model. _Developed a system to cross-reference proposed entities, relationships and attributes with the existing structure of IFC to highlight unique information and those already described by IFC.

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