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A Review on BIM–GIS Integration for Geotechnical Property Modelling and Construction Safety Zoning

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ABSTRACT

BIM and GIS cover different parts of a construction project: BIM describes the facility in detail, and GIS describes the ground and surroundings it sits in. Geotechnical data fall between the two. Soil and rock change across a site and with depth, but this variation seldom reaches project models in a form that helps with safety decisions. We reviewed 17 journal, conference and proceedings papers on BIM–GIS integration, geotechnical data in BIM, three-dimensional subsurface modelling, hazard monitoring and multi-criteria decision support. The studies show that borehole and test data can be interpolated in GIS, moved into BIM software and turned into soil-class or hazard zones. They also share some weaknesses. Results depend heavily on borehole density, interpolation settings are often found by trial and error, meaning is lost when data are exchanged, zoning rules use few parameters, and few studies check their output against field behaviour. From these findings we propose a six-stage workflow that links quality-controlled site data, an engineer-interpreted ground model with stated uncertainty, BIM–GIS integration, documented project-specific zoning criteria and versioned review. It keeps the data, the interpreted ground model, the hazard assessment and the approved site-control zone apart. The workflow is conceptual and has not been tested. We propose no universal thresholds, and any real use would need site data, engineering review and field validation. We close with a validation plan and a list of research priorities.

Keywords—Building Information Modelling (BIM); Geographic Information System (GIS); geotechnical modelling; construction safety zoning; interoperability; uncertainty; spatial decision support; subsurface modelling.

1. Introduction

Any construction decision draws on both the design of the facility and what is known about the site: terrain, geology, groundwater, existing assets, access and neighbouring structures. In most projects these pieces of information sit in different software packages. BIM holds detailed, object-based information about a facility, and GIS holds spatial information over a site or a much wider area. The two grew up for different purposes, which makes combining them useful but awkward. The topic has been reviewed several times, from the viewpoints of integration methods and applications [1], data models and data-level interoperability [2], construction project management [3], and spatio-temporal analysis across the architecture, engineering and construction (AEC) industry [4].

Later work tackles the semantic problem with ontologies and metamodels for asset management [5] and compares open-source and closed-source environments for joining BIM and GIS [6]. Application papers show the payoff once the connection works. Zhao et al. [7] detect conflicts between a planned water pipeline and its surroundings automatically, D'Amico et al. [8] support technical and environmental decisions in transport infrastructure design, and Volk et al. [9], writing about existing buildings, show how hard it is to keep a BIM current when the information it holds is incomplete or uncertain.

Ground conditions need separate attention. They vary in three dimensions, they are known only where someone has drilled or tested, and they bear directly on excavation stability, foundation choice and temporary works. According to Satyanaga et al. [10], geotechnical engineering has taken up BIM more slowly than structural engineering; two-dimensional practice persists, and data volume and exchange formats get in the way. Meira et al. [11] showed that geotechnical parameters can be modelled parametrically in a BIM environment. A few studies go a step further and derive safety-relevant zones, either by interpolating in GIS and visualising in BIM [12], [13] or by building high-resolution 3D ground models for geohazard assessment [14]. Work on soil-resource management [15], on landslide monitoring and early warning with BIM [16], and on multi-criteria decision-making (MCDM) in BIM–geotechnical projects [17] sits around this core.

The literature is nonetheless scattered. General BIM–GIS reviews say little about subsurface data, geotechnical papers say little about how the integration is built, and the few studies that produce safety zones rely on simple rules and limited validation. In the studies we reviewed, nobody has pulled together what the evidence supports for geotechnical safety zoning, and no workflow keeps provenance, uncertainty and accountability for approval together.

We do three things in this paper. We read 17 studies with geotechnical zoning in mind rather than BIM–GIS in general. We collect the quantitative and methodological evidence the application studies report, along with the caveats that go with it. And we propose a conceptual workflow and a validation plan that others can test. The paper is a focused narrative review. It contains no new software implementation and no field-validated safety algorithm.

2. Review Scope and Method

Our basis is a set of 17 publications from 2014 to 2026 that were supplied for this work: articles from geo-information, construction, geotechnical and built-environment journals, plus conference and proceedings papers. We read each one in full and compared them on four points: what the study was for and where it applied, what data and integration approach it used, what it reported, and what limitations or openings it left for geotechnical modelling and zoning. For the application studies we took sample sizes, validation procedures and performance figures exactly as the authors stated them.

We sorted the papers into five themes: (A) BIM–GIS integration foundations [1]–[6]; (B) integration in planning and design [7]–[9]; (C) geotechnical data in BIM [10], [11]; (D) subsurface modelling and zoning [12]–[15]; and (E) hazard monitoring and decision support [16], [17]. The set was supplied to us and not found through a recorded database search, and there was no screening protocol or quality appraisal, so this is a focused narrative review and not a systematic one. It describes these 17 studies, not the whole field. Table 1 lists them.

Table 1. The 17 studies included in this synthesis.

Ref.	Study	Type / domain	Main focus	Relevance to geotechnical safety zoning
[1]	Liu et al. (2017)	Review; BIM–GIS	Differences between BIM and GIS, integration methods and applications; "EEEF" criteria (effectiveness, extensibility, effort, flexibility) for choosing a method	Method-selection criteria; openness identified as key to successful integration
[2]	Zhu et al. (2018)	Review; data level	Data models used in BIM/GIS integration, their advantages and disadvantages	Data incompatibility (coordinates, scope, structure) is the central obstacle
[3]	Wan Abdul Basir et al. (2018)	Review; construction management	GIS as a complement to BIM for managing project information	Drawbacks in data sharing, integration and management
[4]	Song et al. (2017)	Review of 96 articles	Applications and trends from a spatio-temporal statistical perspective	Calls for theory and mathematical modelling beyond integration techniques
[5]	Celeste et al. (2022)	Systematic literature review	Ontologies and metamodels for BIM/GIS integration and asset management	Semantic barriers; joint use of ontologies and metamodels unexplored
[6]	Piras et al. (2024)	Methodological study	Open-source versus closed-source environments for BIM–GIS integration	Flexibility, security and sustainability trade-offs for platform choice
[7]	Zhao et al. (2019)	Application; water distribution	Semantic mapping of BIM data into GIS, 3D visualisation, topological conflict checks; tested on a real project	Transferable approach for conflict checks between excavations and utilities
[8]	D'Amico et al. (2020)	Application; transport infrastructure	BIM–GIS integration for technical and environmental decision-making, including soil cut/fill reuse and maintenance prioritisation	Shows soil-related decisions supported by overlaying design and ground data

Ref.	Study	Type / domain	Main focus	Relevance to geotechnical safety zoning
[9]	Volk et al. (2014)	Review of 180+ publications	BIM for existing buildings: conversion effort, updating, uncertain data	Updating and uncertainty challenges apply equally to changing ground conditions
[10]	Satyanaga et al. (2023)	Review with case studies	Strategies to bring geotechnical data into BIM (BIM–FEM–BIM, IFC, AGS, CSV)	Data formats and data-volume problems in geotechnical BIM
[11]	Meira et al. (2024)	Method / case study	Organising geotechnical test data and modelling subsoil layers parametrically in Civil 3D	Feasibility of parametric ground modelling in BIM
[12]	Khan et al. (2021)	Method / case study	GIS interpolation of borehole data, IFC geotechnical classes, soil-type zoning for excavation	Closest precedent for BIM–GIS safety zoning
[13]	Qahtan & Dakhil (2024)	Method / case study	IDW interpolation of SPT data in GIS, transfer to Civil 3D, soil zones and volumes	Documents interpolation tuning, validation and transfer limits
[14]	Kim & Chung (2026)	Framework / case study	3D geostatistical ground model for geohazard zonation (settlement, liquefaction) feeding Geo-BIM	Explicit uncertainty quantification and hold-out validation
[15]	Borkowski et al. (2024)	Method / case study	Soil-resource data from soil-agricultural maps, terrain and orthophotos for BIM-based documentation	Agricultural rather than geotechnical data; relevant to soil-resource context
[16]	Wang & Xu (2025)	System / experiment	BIM landslide model with weighted-average sensor fusion for monitoring and early warning	Dynamic monitoring layer; performance is author-reported
[17]	Akbas & Akin (2025)	Systematic analysis	MCDM methods used in BIM–geotechnical studies	Menu of decision-support methods and common criteria

Note: study descriptions are drawn from each paper's own abstract and text.

3. Literature Synthesis

3.1 BIM–GIS integration foundations

The general reviews agree that integration is worth doing and that data make it hard. Liu et al. [1] compare existing methods and suggest four criteria for choosing between them: effectiveness, extensibility, effort and flexibility. Semantic-web technologies look promising and general to them, though they take a lot of effort to set up and ontologies tend to be built in isolation. Their conclusion is that openness decides whether integration succeeds. Zhu et al. [2] look at the data level and name incompatibility, in coordinate systems, scope of interest and data structures, as the biggest barrier. Wan Abdul Basir et al. [3] treat GIS as a complement to BIM for managing project information and point to remaining problems with sharing, integrating and managing data.

Song et al. [4] reviewed 96 articles and argued that the field needs theory and mathematical modelling, such as spatio-temporal statistical modelling in GIS and 4D/nD BIM simulation, and not only more work on integration techniques. Celeste et al. [5], in a systematic review, found that ontologies are a promising way past semantic barriers, that metamodels are seldom used, and that nobody had yet combined the two. Piras et al. [6] set open-source against closed-source environments and stress planning and collaboration across architecture, engineering and geoinformatics.

For our purposes the lesson is that integration has to be more than overlaying geometry. A geotechnical workflow must handle coordinate transformation, geometry conversion, attribute mapping and object identity, and it must keep what each measurement means: where it came from, its location, elevation, depth interval, date, test method and interpretation.

3.2 Integration in applied planning and design

Two application studies show what integration can do beyond visualisation. Zhao et al. [7] used semantic mapping to bring BIM data for a water distribution project into GIS, built a 3D model of the project and its surroundings, and wrote topological rules to find conflicts with existing structures. On a real project the method found conflicts before construction. The authors say semantic mapping avoided data loss; that is their claim for their own case. Rule-based spatial checks of this kind could just as well be applied to excavation boundaries, utilities and temporary works.

D'Amico et al. [8] discuss BIM–GIS integration for technical and environmental decisions in transport infrastructure design, prompted by European and Italian regulation that encourages BIM. In their airport example, cut and fill volumes from BIM are laid over an environmental map of soil quality to find soil that could be reused instead of disposed of. They also suggest combining environmental data with BIM maintenance records to set intervention priorities. Soil information supports decisions here in both design and operation, although the questions concern resources and sustainability and not worker safety.

Volk et al. [9] reviewed more than 180 publications on BIM for existing buildings and found three recurring difficulties: converting captured data into semantic BIM objects takes effort, information is hard to keep up to date, and uncertain data, objects and relations are hard to handle. Their subject is buildings, but ground models face the same problems. They are built from sparse observations, they change as excavation proceeds, and they are uncertain by nature.

3.3 Geotechnical data in BIM

Satyanaga et al. [10] reviewed ways of getting geotechnical information into BIM and looked at several case studies: a BIM–FEM–BIM exchange with Plaxis 3D, a hill-fortification model built from many imported boreholes, and two Malaysian studies that modelled a 3D subsurface in the AGS and CSV formats. They found that BIM–FEM exchange can deliver a geometric model that often lacks physical information, and that open formats (IFC with extensions, AGS, CSV) give more flexibility. AGS carries more information than CSV, while CSV supports a more generalised model. Too much information makes the model heavy and complicated, so they recommend summarising large geotechnical datasets while losing as little useful data as possible.

Meira et al. [11] organised geotechnical test results from a case-study area and modelled the subsoil layers parametrically in Autodesk Civil 3D. They conclude that geotechnical parameters can be modelled in BIM and that the area has potential. Akbas and Akin [17] analysed studies that use MCDM in BIM–geotechnical workflows. The Analytic Hierarchy Process (AHP) was used most often, frequently alongside other techniques, and PROMETHEE, DEMATEL, CRITIC, MOORA, MAUT, ELECTRE and DEX also appear. Applications range over tunnelling, excavation support, foundations, landslide assessment and transport infrastructure. Cost, interoperability, time and risk come up most as criteria, and most studies concern design and construction phases.

3.4 Subsurface modelling and safety zoning

Khan et al. [12] is the closest precedent to our topic. They worked with borehole data from Peshawar, Pakistan (SPT-N values, unconfined compressive strength and water-table information), interpolated the parameters in GIS with kriging, and represented boreholes, geotechnical surfaces and solids in BIM through the open IFC classes IfcBorehole, IfcGeoslice and IfcGeomodel. Surfaces and soil volumes were then visualised and calculated in Autodesk Civil 3D. The study area was classified into the OSHA soil categories (stable rock and soil types A, B and C), which are tied to protective systems for excavation such as sloping, benching and shoring; the authors report allowable slopes of 53°, 45° and 34° for types A, B and C. They integrate GIS into BIM only and leave the BIM-to-GIS direction for future work, and they rely on borehole data that already existed.

Qahtan and Dakhil [13] followed a similar chain with 19 boreholes to 45 m depth and 332 SPT results in Basra, Iraq. They did not fix the interpolation settings in advance. The data were split into an interpolation group and a validation group, and the IDW parameters that gave the smallest RMSE were chosen. Contour layers were then moved from GIS to Civil 3D through DWG or IFC, and layer volumes were estimated. Comparing predicted with actual SPT-N values gave coefficients of determination from about 0.77 to 0.99 across six boreholes, with at most one depth per borehole classified differently from the log. Type A soil made up about 73% of the model volume (about 4.41 million m^3) and type B about 27% (about 1.62 million m^3). The authors list three limitations: the search for parameters is trial and error, contour layers have to be transferred by hand, and outlier values within a layer are not captured by the interpolation.

Kim and Chung [14] present the most developed framework from a quantitative point of view. Their data are dense, including 268 borings with SPT and 28 piezocone (CPTu) boreholes. They compared three interpolation methods for soil-layer thickness using leave-one-out cross-validation and obtained RMSE values of 1.6 m for IDW, 1.2 m for ordinary kriging and 0.3 m for sequential Gaussian simulation (SGS). They chose SGS and, after testing grid sizes, a 5 m × 5 m × 1 m grid, and they set aside 15 independent boreholes for out-of-sample validation. The 3D model was coupled with finite-element analysis of consolidation settlement and with liquefaction assessment (including the LPI and LSN indices) to produce 2D/3D hazard zonation maps meant as input to Geo-BIM. The cross-validation RMSE is also used to define an error-adjusted design depth, which is one concrete way of carrying model

uncertainty into a design decision. The authors point out that they could not validate against field monitoring, because no settlement plates, piezometers or accelerometers were available at the site.

Borkowski et al. [15] deal with soil resources and not with geotechnical hazards. They used soil-agricultural maps, soil-quality contours, a digital terrain model and orthophotomaps from a Polish commune to support the management of soil resources and its documentation in BIM, and they note that using GIS data in BIM is difficult because BIM–GIS integration is lacking. The paper shows what site-specific soil data management can look like, but its data are not geotechnical design parameters and cannot support safety classification.

3.5 Hazard monitoring and decision support

Wang and Xu [16] build a BIM-based 3D landslide geology model and add a weighted-average fusion algorithm for multi-sensor monitoring. In their experiments the average monitoring accuracy across five monitoring points was 97.6% with a mean square error of 1.37, and the early-warning success and false-alarm rates were 98.6% and 1.36%, better than the BIM-only and BIM+GIS comparison systems they tested. These results come from the authors' own experiments against comparison systems they chose, and it has not been shown that they carry over to other sites, sensor networks or hazards. We include the study because it brings in a time-varying monitoring layer that the borehole-based zoning studies do not have.

Akbas and Akin [17] show that structured MCDM methods are common in BIM–geotechnical research. The zoning studies we reviewed mostly do something simpler, using soil-type classes derived from SPT or strength [12], [13], or hazard indices computed from analysis results [14]. Choosing between a simple rule and an MCDM scheme is itself a safety-relevant decision, since criteria, weights and thresholds strongly affect the classification that comes out.

4. Synthesis of Reported Evidence

Table 2 brings together the quantitative and procedural evidence from the application studies most relevant to geotechnical zoning. The figures are given as reported. They should not be compared directly, because sites, data densities, targets and validation designs differ.

Table 2. Reported evidence and caveats in the geotechnical and hazard application studies.

Study	Data and tools	Reported evidence	Caveat
Khan et al. [12]	Peshawar boreholes to 40 m; SPT-N, UCS, water table; kriging in GIS; IFC classes; Civil 3D	Soil-type zones (OSHA A, B, C) with reported allowable slopes of 53°, 45° and 34°	Proof of concept on existing consultant data; GIS-to-BIM direction only
Qahtan & Dakhil [13]	19 boreholes to 45 m; 332 SPT results; IDW; Civil 3D	R^2 about 0.77–0.99 across six boreholes; type A about 73% and type B about 27% of about 6.03 million m^3	SPT-only zoning; manual layer transfer; parameter search by trial and error
Kim & Chung [14]	268 borings with SPT and 28 CPTu boreholes; 5 m × 5 m × 1 m grid	LOOCV RMSE: IDW 1.6 m, OK 1.2 m, SGS 0.3 m; 15 independent validation boreholes	No field-monitoring validation; accuracy depends on data density
Wang & Xu [16]	BIM landslide model; five monitoring points; weighted-average fusion	Accuracy 97.6%; MSE 1.37; warning success 98.6%; false alarms 1.36%	Author-defined comparison systems; transferability not shown
Zhao et al. [7]	Real water distribution project; BIM to GIS semantic mapping; topological rules	Conflicts between pipeline and surroundings identified before construction	Utility-planning case; not geotechnical
Satyanaga et al. [10]	Case studies using BIM–FEM–BIM, IFC, AGS and CSV	Open formats improve flexibility; excess data overloads models	Qualitative findings; formats trade detail against generality

Abbreviations: SPT, standard penetration test; UCS, unconfined compressive strength; CPTu, piezocone penetration test; IDW, inverse distance weighting; OK, ordinary kriging; SGS, sequential Gaussian simulation; LOOCV, leave-one-out cross-validation; MSE, mean square error.

Four patterns stand out. First, the interpolation method matters. In the one study that compared methods directly [14], prediction error differed by a factor of more than five between IDW and SGS, and in another [13] results depended on tuned parameters. Second, the zoning logic in the studies that derive safety zones is simple: soil classes from SPT or strength values [12], [13]. Groundwater, surcharge, adjacent structures and construction stage, which also

affect excavation safety, are not reported as part of that logic. Third, validation is mostly internal, through cross-validation, comparison with logs or comparison with other systems, and not against field performance or an independent expert risk assessment. Fourth, practical data problems keep appearing: choice of format and data volume [10], manual data transfer [13], and loss of semantics [2], [7].

5. Research Gaps

We see seven gaps that a geotechnical safety-zoning workflow should address. Table 3 sets each against its evidence and against the response built into the framework in Section 6.

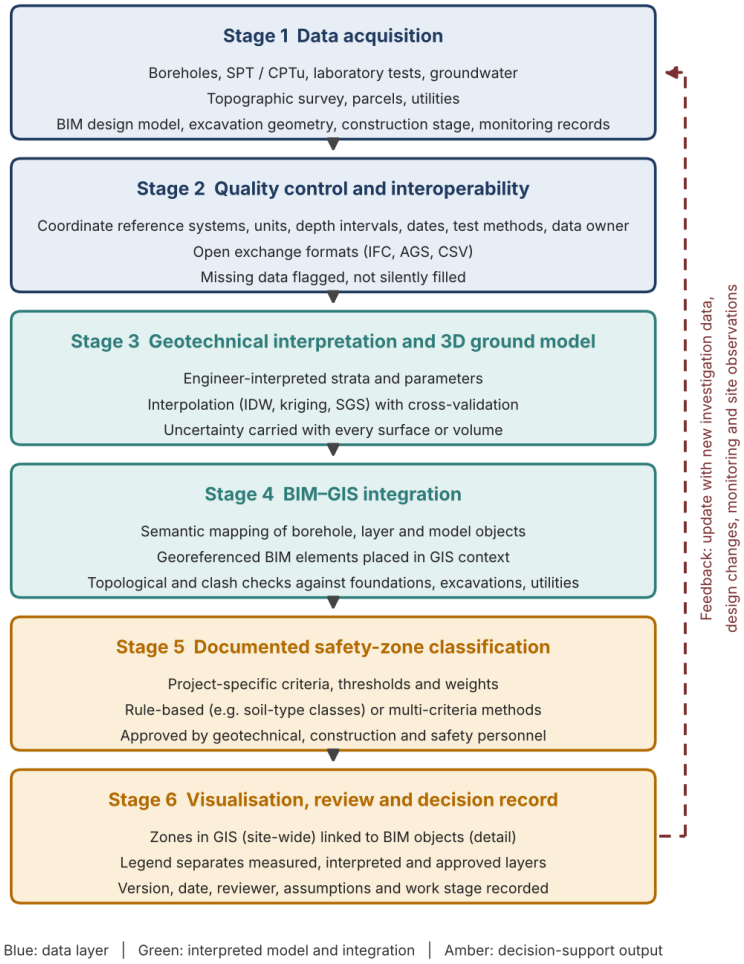
Table 3. Research gaps and corresponding framework responses.

Gap	Evidence in the reviewed studies	Framework response
1. Data interoperability and semantics	Incompatible coordinates, scopes and structures [2]; semantic barriers [5]; format and volume issues [10]; manual transfer [13]	Stage 2 quality control; open formats; semantic mapping of borehole, layer and model objects in Stage 4
2. Integration direction	Zoning studies integrate GIS into BIM only [12], [13]; semantic BIM-to-GIS mapping demonstrated elsewhere [7]	Two-way exchange: ground model into BIM, BIM elements into GIS context
3. Narrow zoning logic	Zones from soil class or SPT [12], [13]; hazard indices from analysis in [14]	Stage 5 project-specific criteria agreed with geotechnical, construction and safety personnel
4. Uncertainty communication	Interpolation errors differ substantially by method [14]; outliers not captured [13]; sparse-data risk [14]	Stage 3 carries uncertainty with each surface; sparse-data areas flagged; error-adjusted values where design depends on them
5. Dynamic context	Updating and uncertainty challenges [9]; monitoring-based warning [16]	Feedback loop for new data, construction stage and monitoring; versioned outputs
6. Validation against field behaviour	No field-monitoring validation in [14]; proof-of-concept in [12]; author-defined baselines in [16]	Validation plan in Section 8 with expert and field comparison
7. Governance and traceability	Decision-support results depend on criteria, weights and thresholds [17]	Stage 6 record of version, reviewer, assumptions, work stage and approval

6. Proposed BIM–GIS Workflow for Geotechnical Safety Zoning

From these themes we propose a six-stage conceptual workflow (Figure 1). It is a framework for future implementation. It has to be calibrated and validated before anyone uses it on a live construction project, and it does not replace statutory requirements, design checks or a site-specific safety plan.

Figure 1. Conceptual BIM–GIS workflow for geotechnical modelling and safety zoning



6.1 Stage 1: Data acquisition

Collect borehole logs, trial-pit records, laboratory and in-situ test results (such as SPT and CPTu), groundwater observations, geological information, the topographic survey, site boundaries, existing utilities, planned foundations, excavation geometry, access routes and construction-stage information, plus any monitoring records. Each item should record its coordinate reference system, units, date, data owner and a quality flag.

6.2 Stage 2: Quality control and interoperability

Before any modelling, check coordinate reference systems, units and depth intervals, and look for duplicate or inconsistent records. Choose exchange formats with the trade-off reported in [10] in mind: richer formats keep more geotechnical meaning, while simpler ones generalise better but carry less. Missing or inconsistent data should be documented and not quietly filled in. Large datasets should be summarised so that the information needed for engineering decisions survives [10].

6.3 Stage 3: Geotechnical interpretation and 3D ground model

The responsible geotechnical engineer interprets the strata and parameters and decides whether interpolation is appropriate. Where it is used, the method and its settings should be chosen through a documented validation procedure and not by habit, because the reported errors differ a great deal between methods [13], [14]. Every interpreted surface, layer or grid cell should keep its source data, its limitations and a measure of uncertainty, for example a cross-validation error or a mask over sparsely investigated areas. Interpreted models should be labelled as interpretations; they do not replace the engineer's assessment.

6.4 Stage 4: BIM–GIS integration

Put the project model and the geographic layers into one spatial reference. Represent boreholes, geotechnical surfaces and solids with open classes where they exist, such as IfcBorehole, IfcGeoslice and IfcGeomodel [12], and use semantic mapping so that attributes survive the exchange [7]. Map BIM elements (foundations, retaining systems, excavation boundaries, temporary works and access routes) to their GIS context. Check alignment against known control points, and apply topological checks like the pipeline-conflict rules in [7] to flag excavations that cut through utilities, structures or areas of poor ground.

6.5 Stage 5: Documented safety-zone classification

Define the criteria for the project together with the geotechnical engineer, construction manager and safety personnel, and record the criteria, thresholds, weights (if a multi-criteria method is used) and the approving authority. Table 4 lists candidate categories with the precedent found in the reviewed studies. We do not propose universal thresholds. Soil-type classes such as the OSHA categories used in [12] and [13] should be treated as one input among several, and outside the United States the locally applicable excavation-safety and geotechnical standards should be used.

Table 4. Candidate zoning criteria categories and their precedents in the reviewed studies.

Criteria category	What it represents	Precedent
Soil or rock class	Classification from SPT, strength or description used to select excavation protection	[12], [13]
Settlement and liquefaction indicators	Ground-response hazards from analysis of 3D ground properties	[14]
Groundwater	Water-table level and its spatial variation	[12] (collected as site data)
Spatial conflict	Overlap of excavation or works with utilities, structures or constrained space	[7]
Monitoring-based warning	Time-varying displacement or sensor signals	[16]
Uncertainty and data coverage	Prediction error and distance to investigation points	[13], [14]
Multi-criteria weighting	Structured combination of cost, risk, time and interoperability criteria	[17]

The categories are drawn from the reviewed studies; selection and weighting are project decisions.

6.6 Stage 6: Visualisation, review and updating

Show zones in GIS for site-wide context and link them to BIM objects for detailed coordination. Legends should separate measured data, interpreted surfaces and decision-support outputs. For every output, record the model version, review date, responsible person, assumptions and work stage. Update the model when new investigation data, design changes, monitoring records or site observations arrive [9], [16].

7. Discussion

The main advantage of the workflow is that it connects ground information, project elements and geographic context in a structured way. GIS handles site-wide spatial analysis and communication, and BIM attaches findings to foundations, excavations and other elements. The application studies we reviewed suggest that this chain is technically feasible: it has produced soil-class zones and volumes [12], [13], inputs for hazard zonation [14] and automated conflict checks [7].

Integration does not make a site safer by itself. Wrong coordinates, poor investigation data, unsuitable interpolation or unreviewed thresholds all produce misleading output. The error differences in [14] show that the choice of interpolation alone can change predicted layer thickness considerably, and the limitations listed in [13] show how much manual work and judgement the process still needs. A safety-zone map is decision support. It does not decide on its own that work is safe, and engineering judgement, regulations, method statements and site-specific risk assessments stay essential.

It is also useful to distinguish a hazard map from a construction safety zone. A hazard map shows a condition or a possible source of harm. A safety zone turns that information into guidance for a particular activity, stage or exposure scenario, and the step needs stated assumptions and someone accountable

who approves it. Future implementations should keep the data layer, the interpreted ground model, the hazard assessment and the approved site-control zone apart instead of merging them into one opaque colour map.

Two more points matter for practice. Data collected for resource or sustainability purposes [8], [15] can be reused for planning, but they are not automatically suitable for safety classification. And since borehole-based models are only as reliable as the investigation density behind them [14], the workflow should also show where extra investigation would cut uncertainty most, not just display what is already known.

8. Validation Plan for Future Research

To turn the framework into an applied study, the workflow needs to be tested on a documented case. We suggest the following steps.

1. Select a site with geotechnical investigation data, a BIM model and relevant GIS layers.
2. Document data sources, coordinate reference systems, conversion tools, parameter units and quality checks.
3. Build the geotechnical model and link its layers or objects to the BIM–GIS environment, choosing interpolation methods by documented cross-validation, with part of the investigation data withheld for independent testing as in [14].
4. Define safety-zone criteria with qualified project personnel and document the rationale for thresholds or weights.
5. Compare the integrated output with the existing site risk assessment, expert review or an expert-validated reference.
6. Evaluate positional alignment, attribute completeness (loss of attributes in exchange), prediction error, class agreement with borehole logs [13], conflict-detection results [7], processing time and update effort.
7. Where monitoring data exist, compare predicted behaviour with observations, and report false-alarm and missed-detection behaviour for any warning component [16].
8. Report limitations, sensitivity to input data and the effect of uncertainty on zone boundaries.

We report no performance values for the proposed workflow because we generated no case-study dataset, software implementation or validation results. Such values belong in a later paper, after the workflow has been implemented and evaluated.

9. Limitations

This is a focused narrative review and conceptual framework built on 17 supplied publications. It has no reproducible systematic database search, no formal risk-of-bias appraisal, no original field measurements, no software implementation and no empirical validation. The set mixes journal articles with conference and proceedings papers of different review rigour and scope, spans 2014 to 2026, and includes studies whose results are self-reported against comparison cases the authors defined [16]. The values in Table 2 come from different sites and designs and should not be compared directly. The proposed workflow is a research proposition, not a certified method for deciding whether construction is safe.

10. Conclusion

The studies we reviewed show that BIM–GIS integration can connect detailed construction models with geographic and subsurface context, and that borehole and test data can be turned into soil-class zones, volumes and inputs for hazard zonation. They also show where current approaches fall short: interoperability and data volume, interpolation settings found by trial and error, simple zoning rules, and little validation against field behaviour. We propose a six-stage workflow that keeps provenance, uncertainty, documented project-specific criteria and accountable review together, and that separates the data layer, the interpreted ground model, the hazard assessment and the approved site-control zone. Whether it proves useful will depend on traceable data, explicit uncertainty, criteria that suit local conditions and validation by qualified professionals. The next step is to implement it on a documented case study and assess its accuracy, usability and agreement with expert-approved safety assessments before any operational use.

References

[1] X. Liu, X. Wang, G. Wright, J. C. P. Cheng, X. Li, and R. Liu, "A State-of-the-Art Review on the Integration of Building Information Modeling (BIM) and Geographic Information System (GIS)," *ISPRS Int. J. Geo-Inf.*, vol. 6, no. 2, Art. no. 53, 2017, doi: 10.3390/ijgi6020053.

[2] J. Zhu, G. Wright, J. Wang, and X. Wang, "A Critical Review of the Integration of Geographic Information System and Building Information Modelling at the Data Level," *ISPRS Int. J. Geo-Inf.*, vol. 7, no. 2, Art. no. 66, 2018, doi: 10.3390/ijgi7020066.

[3] W. N. F. Wan Abdul Basir, Z. Majid, U. Ujang, and A. Chong, "Integration of GIS and BIM Techniques in Construction Project Management – A Review," *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, vol. XLII-4/W9, pp. 307–314, 2018, doi: 10.5194/isprs-archives-XLII-4-W9-307-2018.

[4] Y. Song, X. Wang, Y. Tan, P. Wu, M. Sutrisna, J. C. P. Cheng, and K. Hampson, "Trends and Opportunities of BIM-GIS Integration in the Architecture, Engineering and Construction Industry: A Review from a Spatio-Temporal Statistical Perspective," *ISPRS Int. J. Geo-Inf.*, vol. 6, no. 12, Art. no. 397, 2017, doi: 10.3390/ijgi6120397.

[5] G. Celeste, M. Lazoi, M. Mangia, and G. Mangialardi, "Innovating the Construction Life Cycle through BIM/GIS Integration: A Review," *Sustainability*, vol. 14, no. 2, Art. no. 766, 2022, doi: 10.3390/su14020766.

[6] G. Piras, F. Muzi, and C. Zylka, "Integration of BIM and GIS for the Digitization of the Built Environment," *Appl. Sci.*, vol. 14, no. 23, Art. no. 11171, 2024, doi: 10.3390/app142311171.

[7] L. Zhao, Z. Liu, and J. Mbachu, "An Integrated BIM–GIS Method for Planning of Water Distribution System," *ISPRS Int. J. Geo-Inf.*, vol. 8, no. 8, Art. no. 331, 2019, doi: 10.3390/ijgi8080331.

[8] F. D'Amico, A. Calvi, E. Schiattarella, M. Di Prete, and V. Veraldi, "BIM and GIS Data Integration: A Novel Approach of Technical/Environmental Decision-Making Process in Transport Infrastructure Design," *Transp. Res. Procedia*, vol. 45, pp. 803–810, 2020, doi: 10.1016/j.trpro.2020.02.090.

[9] R. Volk, J. Stengel, and F. Schultmann, "Building Information Modeling (BIM) for existing buildings – Literature review and future needs," *Autom. Constr.*, vol. 38, pp. 109–127, 2014, doi: 10.1016/j.autcon.2013.10.023.

[10] A. Satyanaga, G. D. Aventian, Y. Makenova, A. Zhakiyeva, Z. Kamaliyeva, S.-W. Moon, and J. Kim, "Building Information Modelling for Application in Geotechnical Engineering," *Infrastructures*, vol. 8, no. 6, Art. no. 103, 2023, doi: 10.3390/infrastructures8060103.

[11] T. M. R. Meira, L. S. P. Cardoso, B. F. Silveira, and L. J. R. Rosa, "Modelling Geotechnical Parameters in BIM," in *Proc. X Int. Symp. Innovation and Technology*, 2024. [Verify publisher, page range and DOI before submission.]

[12] M. S. Khan, J. Park, and J. Seo, "Geotechnical Property Modeling and Construction Safety Zoning Based on GIS and BIM Integration," *Appl. Sci.*, vol. 11, no. 9, Art. no. 4004, 2021, doi: 10.3390/app11094004.

[13] R. Z. Qahtan and A. J. Dakhil, "3D visualization of interpolating geotechnical strata in a BIM environment and estimating the volume," *Misan J. Eng. Sci.*, vol. 3, no. 2, Dec. 2024, doi: 10.61263/mjes.v3i2.82.

[14] H.-S. Kim and T.-K. Chung, "Integrating 3D geotechnical characterization and Geo-BIM for geohazard assessment in soft ground," *Dev. Built Environ.*, vol. 25, Art. no. 100863, 2026, doi: 10.1016/j.dibe.2026.100863.

[15] A. S. Borkowski, A. Bielska, and J. Kwiatkowska-Malina, "Site-specific efficient management of soil resources using GIS and BIM technologies," *Rep. Geod. Geoinf.*, vol. 117, pp. 89–98, 2024, doi: 10.2478/rgg-2024-0009.

[16] Z. Wang and M. Xu, "Geological Hazard Monitoring and Early Warning Based on BIM Technology and Multiple Information Integration," in *Civil Engineering and Smart Structure Technology*, W. Yao et al., Eds. IOS Press, 2025, doi: 10.3233/ATDE250227. [Verify series, volume and page range before submission.]

[17] M. Akbas and F. D. Akin, "A Systematic Analysis of Multi-Criteria Decision-Making Methods in BIM–Geotechnical Integration," presented at the 5th Int. Cankaya Scientific Studies Congress, Ankara, Türkiye, Dec. 8–9, 2025. [Verify proceedings publication details before submission.]