GUIDE 01

VDC FORUM
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COORDINATES: *THEN COORDINATION*

for Virtual Design and Construction (VDC) Projects with Building Information Modeling (BIM)

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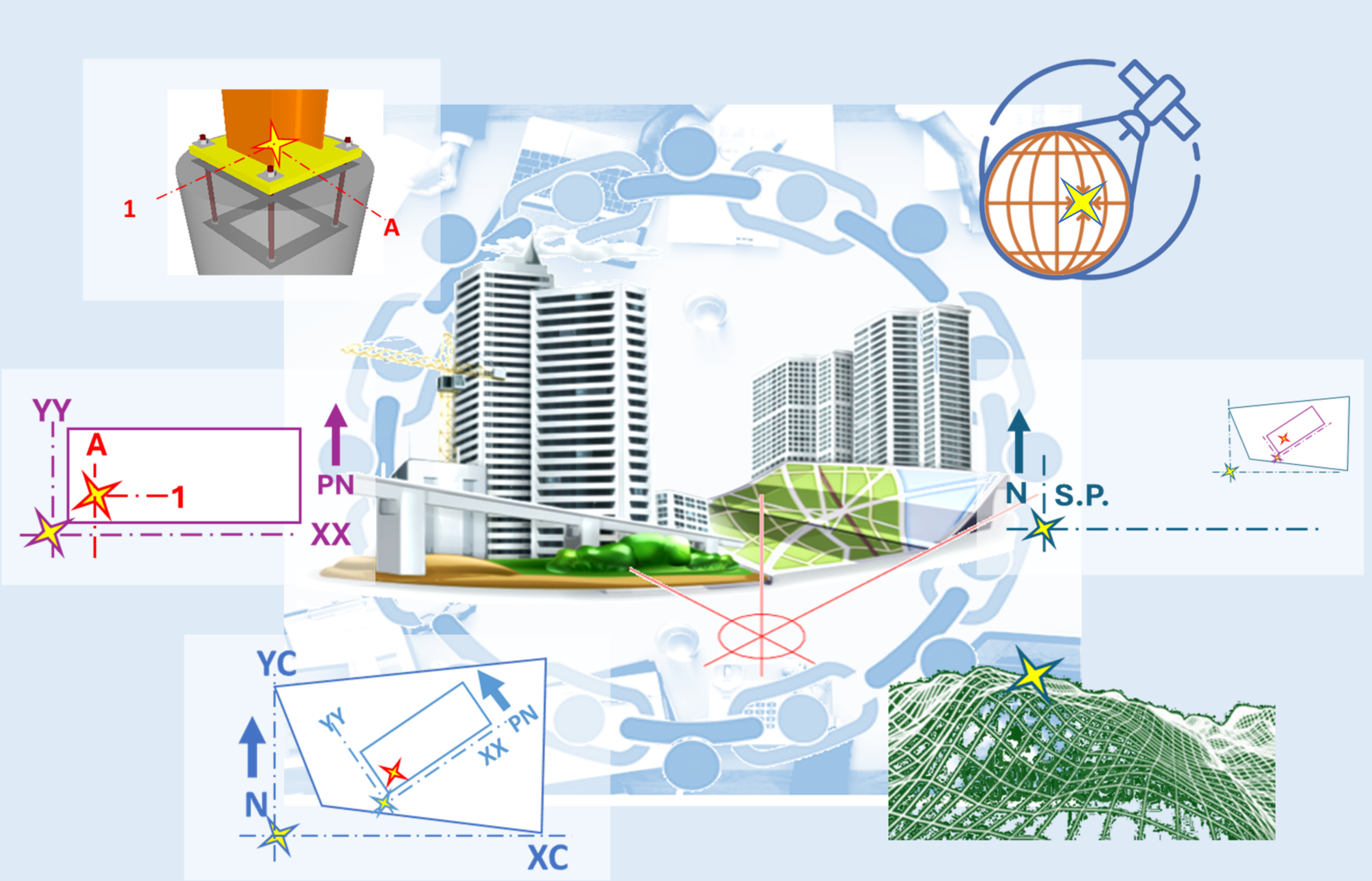

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VDCForum Guide

#01: Coordinates: *Then Coordination*

for Virtual Design and Construction (VDC) Projects
with Building Information Modeling (BIM)

October 2025 Initial Draft, January 2026 Public Review Draft

1. Executive Summary

Virtual Design and Construction (VDC) with Building Information Modeling (BIM) relies fundamentally on the clear definition, management, and communication of coordinates. Yet across the building industry, coordinate systems are frequently under-defined or inconsistently applied, leading to misalignment between disciplines, unreliable models, constructability conflicts, rework, and erosion of confidence in digital deliverables. **VDCForum Guide #01:** "***Coordinates, Then Coordination***" establishes a rigorous, discipline-agnostic framework to address this persistent problem.

This guide introduces C.A.P.U.T.—derived from the Latin caput, meaning head, source, or principal point—as the foundational construct for spatial reliability in BIM and VDC. CAPUT represents Coordinates, Accuracy, Precision, Units, and Tolerances. These five elements are inseparable; when they are defined and applied together, spatial data becomes stable and trustworthy throughout the project lifecycle. When they are not, coordination becomes kaputt (German origin)—broken—resulting in ambiguity, misinterpretation, and downstream failure.

The core premise of this guide is direct: there can be no coordination without first establishing coordinates. Model Elements (MEs) cannot be defined beyond approximate location and orientation unless a clearly documented coordinate system exists. Claims of advanced coordination, high Levels of Development (LOD), or constructability validation are technically indefensible without this foundation.

The guide documents the six primary coordinate systems used in BIM-based projects—[1] Element (Object), [2] Project (Building), [3] Campus (Site), [4] State Plane (Grid), [5] Surface (Ground), and [6] Global Positioning System (GPS)—and explains their distinct purposes, relationships, and proper use. It clarifies how these systems interact, how they are transformed between relative and absolute references, and why misunderstanding these relationships is a common source of project error, particularly on large or complex sites.

This guide addresses the role of the Internal Origin in 3D modeling software. The Internal Origin governs numerical precision, computational stability, model performance, and interoperability. Modeling far from this origin introduces floating-point errors that directly undermine accuracy and tolerance control. The guide provides best-practice conventions for origin placement, quadrant use, and model setup that support multidisciplinary coordination and reliable data exchange in each of the main 6 coordinate systems.

Beyond coordinates alone, the guide explicitly connects coordinate systems to accuracy, precision, units, and tolerances, emphasizing that numeric detail without correctness is meaningless, and precision without tolerance awareness is misleading. It addresses critical industry issues such as State Plane versus Surface coordinates, grid-to-ground correction factors, and U.S. Survey Foot versus International Foot usage.

VDCForum Guide #01 is not software-specific and does not replace professional judgment or contractual requirements. It provides a common technical language and framework to align owners, designers, contractors, and trade partners. Its central assertion is clear: coordinates are the governing structure of BIM and VDC. When CAPUT is clearly defined and consistently applied, coordination succeeds; when it is not, even the most advanced digital tools cannot compensate.

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2. Background

This guide was developed the with insights from over a hundred case study projects conducted by Ascend Building Knowledge Foundation (AscendBKF) beginning in 2017 with analysis complemented by its forums of BIMForum Global and VDCForum beginning in 2023. The challenges, issues, and solutions related to coordinates and coordinate systems have been summarized in this guide. The project types include, but are not limited to, international airports, data centers, chip manufacturing facilities, office buildings, hospitals, industrial facilities, banks, houses of worship, K-12 schools, universities, biotech, pharmaceutical, chemical facilities, food processing, water and waste water treatment, bridges, county and federal courts buildings, corporate headquarters of publicly traded companies, transportation infrastructure, land development, and other infrastructure projects in the built environment. Due to the nature of the projects, a majority of the teams have at least some members who wish the projects to remain anonymous and this guide honors their request. Other projects are under non-disclosure agreements for security purposes, and those case study interviews did not disclose any information covered under NDA while team members were able to share issues and challenges their teams faced in a general nature on such projects. The case study research is contained internally with only summaries and recommendations of findings provided in this guide.

3. Introduction

3.1. C.A.P.U.T.

> *Caput, Capitis n. (Latin Origin, keɪ.pət):*
> *1. Source, origin, or principal point.*
> *2. An acronym for **C**oordinates, **A**ccuracy, **P**recision, **U**nits, and **T**olerances —defines the foundational elements required for reliable spatial information & coordination in the built environment with Virtual Design and Construction (VDC) with Building Information Modeling (BIM).*

In this guide, **CAPUT** is derived from the Latin *caput*, meaning *head*, *source*, or *principal point of reference*. It represents the governing framework for coordinate definition in BIM and VDC, integrating coordinates, accuracy, precision, units, and tolerances into a single, disciplined approach. By addressing each component collectively rather than in isolation, CAPUT emphasizes that coordinate integrity depends not on any single parameter, but on the disciplined alignment of coordinate systems, numerical accuracy, measurement precision, unit consistency, and clearly defined tolerances. This guide uses the CAPUT framework to establish a common technical language and set expectations for all stakeholders responsible for creating, exchanging, and relying upon spatial data. *CAPUT est caput rei in BIM et VDC* (CAPUT is the principal matter in BIM and VDC). When these elements are clearly defined and consistently applied, spatial data remains stable and trustworthy throughout the project lifecycle—the natural outcome of CAPUT properly applied. When they are not, coordination becomes *kaputt* (the German word for *broken*), leading to misalignment, rework, and erosion of confidence in the model.

3.2. Thesis: CAPUT is the principal matter within BIM & VDC

"He who does not know his origin will never reach his destination." — African proverb

Thesis: Clear CAPUT definitions are fundamental to the success of any Virtual Design & Construction (VDC) project with Building Information Modeling (BIM). It is the position of this guide that without a clear definition of a model origin, every measurement is a guess, and no model elements are beyond approximate for orientation and location. The major aspects of a coordinate system are [1] *Coordinates (C)*, [2] *Accuracy (A)*, [3] *Precision (P)*, [4] *Units (U)*, and [5] *Tolerances (T)*. Coordination requires communication of the coordinate system to all stakeholders.

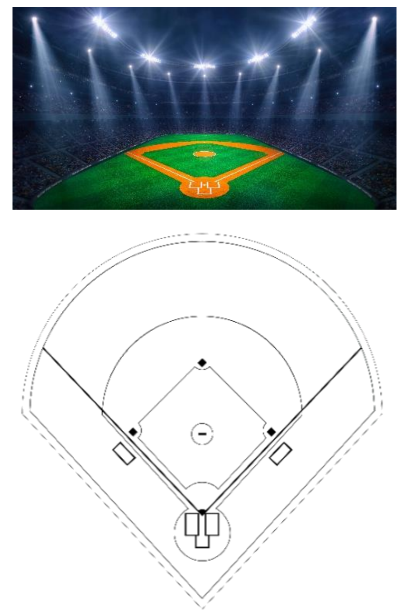

Figure 1: The coordinate system is the critical link that creates order from model chaos. For a project team to not have a well-defined coordinate system is like a team attempting to play baseball or soccer without boundaries or bases. While team members can spend time playing around by themselves without boundaries and bases, it is not how professional leagues compete.

Success in Virtual Design and Construction (VDC) with BIM lies in a rigorous, clearly defined coordinate system from inception of concept, through design, into construction, and beyond in facility management. The coordinate system is the critical link that creates order from model chaos. For a project team to not have a well-defined coordinate system is like a team attempting to play baseball or soccer without boundaries or bases. While team members can spend time playing around by themselves without boundaries and bases, it is not how professional leagues compete. Far from being a mere technicality, a well-planned coordinate system is the invisible thread that connects every element of a project, from the initial schematic design, to the final, constructed building. It creates order for every design team member, every trade, and every piece of data so that the models are 'speaking' the same 'language and grammar' of location and orientation. There must be a defined coordinate system before scales such as Level of Detail or Level of Development (LOD) can be used to communicate an object is in a specific location and orientation. ***It is the position of this guide that it is not practically possible to state an object at an LOD above 200 (approximate) for location and orientation unless the coordinate system is defined.*** Ideally, the coordinate system used in design should be defined in the design team's construction documents between civil (C), architectural (A), structural (S), and mechanical/electrical/plumbing (MEP). Additionally, when the construction team defines the control for the project, they too should clearly communicate their coordinate systems to the trade partners along with the relationship to the design team's coordinates that are prescribed in the construction documents. Without this unified framework, projects are susceptible to misalignment, costly rework, and, in some cases, catastrophic errors. This guide is designed to demystify these critical concepts and provide a practical blueprint for their implementation.

Building on these fundamentals, this guide will explain the six different coordinate systems that exist when the first element is modeled for an object to be placed in the real world along with an explanation of their distinct purposes. This includes the global systems of civil State Plane (Grid, Plane), civil surface (Ground, Surface), and Global Position System (GPS) coordinates and how they relate to more localized systems used for specific aspects of the design such as Object, Project, and Site/Campus coordinate systems. Additionally, the guide will discuss how the concepts that define the quality of project data relate to coordinates such as Level of Detail/Level of Development (LOD), Level of Acceptance (LOA) for reality capture, augmented reality (AR), and scan-to-BIM (S2B). These constructs directly influence a project's setup and a team's ability to support various phases of the design/construction/operations lifecycle in BIM. These constructs should be clearly defined in a Project Execution Plan's VDC section that defines BIM use.

Finally, all these elements will be brought together into a comprehensive framework for project setup. By the end of this guide, you will have a clear understanding of how these different coordinate systems, standards, and levels of definition work in concert to create a rigorous and reliable foundation for your work in VDC with BIM. ***A thoughtful and deliberate approach to coordinate system setup is not just a best practice, it's an essential component of professional excellence and the most effective way to create an environment for a seamless and successful project from start to finish that utilizes BIM.***

3.3. Coordinates, Not New, Often Missed in Modern Projects

The coordinate systems this guide addresses began with Euclid around 300 BC and were expanded and innovated by Rene Descartes in the 1700's. However, many building owners, designers, and builders struggle in BIM coordination over communicating and utilizing the foundational concept of coordinates today in the 2020's. This is seen in architectural and engineering Construction Documents that fail to confirm to the laws of geometry or lack the coordinate information to accurately document the design intent they are attempting to show. *It appears some building industry teams have learned little over the last two millennia about geometry.*

3.4. Coordination in VDC with BIM

"Coordinates Then Coordination"
Author

Coordination of the built environment requires elements to be sufficiently represented beyond "approximate" in models (LOD greater than 200), especially for constructability coordination. The components of CAPUT are the foundational constructs that allow a building object (Model Element) to be defined beyond merely an approximate representation in a Building Information Model (BIM). It is the position of this guide that teams cannot have coordination without a clearly defined coordinate system; "*coordinates, then coordination."*

4. Systems Origins & Recommended Conventions

The establishment of a definitive origin point within a 3D modeling environment is foundational to all geometric computation and spatial referencing. A rigorously defined origin—typically expressed as (0,0,0)—provides the datum for object placement, orientation, scaling, and spatial relationships. Without this reference, modeling software lacks a consistent geometric framework, resulting in ambiguity and instability in downstream processes. The origin defines the geometric meaning of topological entities—vertices, edges, and faces—collectively referred to as *Model Elements (ME)*, and serves as the anchor for the entire digital model.

4.1. Internal Origin

The Internal Origin (IO) is the foundational reference of a model's internal coordinate system that may not be initially exposed to the user in the 3D software. Other coordinate systems—such as local Building or global Civil/Survey systems—are established relative to the IO through defined offsets and rotations. Clear definition and consistent management of these relationships are essential to maintaining spatial integrity between different 3D software applications.

In BIM workflows, disciplined control of the Internal Origin is critical for multidisciplinary coordination. Models authored by architectural, structural, MEP, and civil disciplines—often using different platforms — require consistent origin relationships for accurate alignment relative to each models IO. Proper use of the IO enables reliable clash detection, quantity takeoffs, and constructability analysis, reducing coordination errors and ensuring the federated model reflects design intent.

4.2. Error Modeling Far From the IO

Modeling proximity to the internal origin is also essential for numerical precision. BIM software relies on floating-point arithmetic, and increasing distance from the origin increases susceptibility to rounding errors. Modeling near the IO improves accuracy for fine-grained geometry and tight tolerances, supporting precise alignment of structural elements, MEP routing, and prefabricated assemblies. Best-practice distance thresholds vary by the type of building elements being represented, from large civil sites with thousands of acres modeled millions of feet from the civil software IO to high-precision assemblies like unitized curtain wall extrusion measured in mills (0.0001 inches) which are best modeled with their assembly at the IO.

4.3. Quadrant 1, Best Practice with Positive Coordinates

Modeling within Quadrant I (positive X, Y, Z coordinates) is commonly recommended due to long-standing CAD conventions and improved consistency across project teams. While modern software can operate in any quadrant, adherence to Quadrant I modeling has several advantages. There are still some applications used in industry that do not handle negative distances well.

However, the most practical reason for modeling in quadrant 1 coordinates is that it avoids negative numbers for the humans designing and constructing the model elements.

4.4. Typical Coordinate Systems Relative to IO

These principles form the basis of the project's local relative Building coordinate system, which may become part of the contractual definition of the model and its associated LOD. The design BIM section of the Project Execution Plan (BxP/BEP) shall document the project origin and coordinate relationships and be transmitted with the models to the owner and construction team. Early definition provides a consistent reference for downstream trade, fabrication, and field layout models. Project do utilize a full range of coordinate system whether the BxP/PEP explicitly documents it or not. These are (1) Element / Object, (2) Project / Building, (3) Campus / Site, (4) State Plane / Grid, (5) Surface / Ground, and (6) GPS coordinate systems. Model Elements in building and structures are typically defined relative to the local Project or Building coordinate system using grid and elevation offsets. For civil content, model elements are typically located relative to the state-plane/grid or surface/ground coordinate system with Northing, Easting, and elevation offsets. When these relationships are clearly documented, models can be reliably transformed between relative and absolute systems. Ground coordinates are most important for real-world measurements using reality capture such as laser scanning on large projects. Owners are encouraged to require clear documentation of all coordinate system relationships within the BxP. The following section expands on these 6 fundamental coordinate systems.

5. The 6 Primary Coordinate Systems in BIM for VDC

In summary, these 6 coordinate systems are:

5.1. Element (Object)

Element (Object) Coordinate. This coordinate is the origin of the part or assembly object that is placed in a BIM with other elements relative that BIM's internal origin. For example, the Air Handling Unit (AHU) of a mechanical system will have a relative Element (Object) coordinate that references the internal origin of the BIM it is placed in. The coordinate local Building coordinate, which defines the mechanical room it resides in.

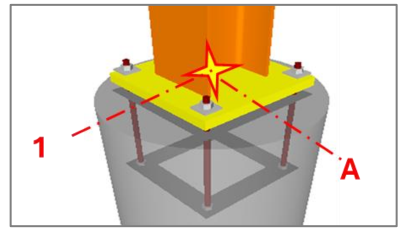

Figure 2: Element (Object) Coordinate. This coordinate is the origin of the part or assembly that is placed in a BIM with other elements relative that BIM's internal origin.

5.2. Project (Building) Coordinates

Relative coordinate system of the building is defined so that the entire building is in positive point coordinates, i.e. Quadrant 1 of the Cartesian coordinate plane for positive values in X, Y and Z.

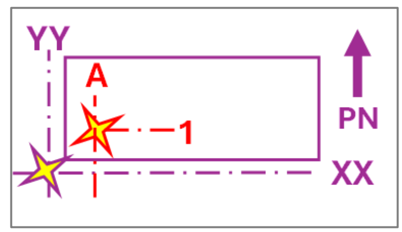

Figure 3: Element Coordinates at grid intersection A-1 are relative to Project Coordinates XX,YY.

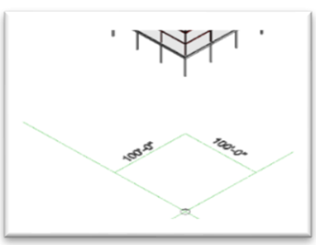

Figure 4: 3D isometric view showing origin clearly defined. Building finish floor is at Z = 100 ft.

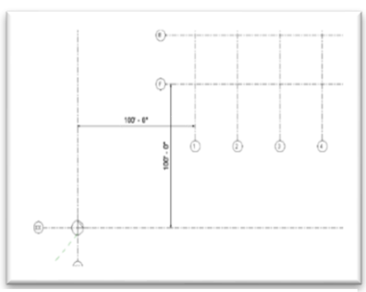

Figure 5: Plan view showing origin clearly defined. Note that the building grid is in a positive quadrant 1 with a consist offset of 100 ft X, and 100 ft y for the intersection of grid F-1.

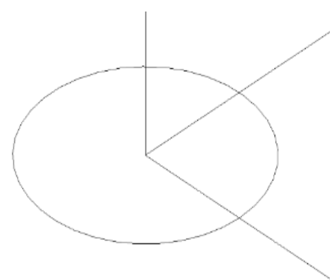

Figure 6 Origin linework that shows in both plan and 3D view of models. This marker should be in the site plan of the Construction Drawings for the project as the contractual definition of the Building Coordinates.

5.2.1. Project (Building) Local - Coordinates

The project general notes of the design drawings and specifications should clearly define the local relative Building X, Y, Z coordinates that other trades will use in construction and that are coordinated with the structural model. Generally, the X, Y coordinates of the origin should be defined relative to the southwest-most column grid intersection with a south and west offset of 10, 100, or 1,000 feet depending on the project size. The southwest column intersection is chosen so the structure is in a positive X, Y coordinate system (i.e. Quadrant 1 of a Cartesian coordinate grid system). The offsets of 10-ft, 100-ft, or 1,000-ft south and west of the origin are so that any portions of the building that extend south or west of the project origin grid intersections will also be within a positive X, Y coordinate system, reference figures 3-7 in this section. Plan North is established as being in the positive Y direction. Many firms will define grids “XX” and “YY” that locate the Origin point of 0,0 relative to the project’s other grid systems shown in the construction documents. Additionally, these elements should be modeled to scale without rounding in their associated dimension strings.

5.2.2. Project (Building) Local - Elevations

The Z elevation should typically be defined as 100-ft, or absolute elevation depending on firm preference for the Local Building Coordinates used for A/S/MEP design of the building or infrastructure. It is common to use a relative 100-ft elevation. The one noted exception to the relative 100 elevation that teams expressed is if a projects site is at an absolute elevation above sea level that is confidently around 100 feet, then it is best to base the project on absolute elevations for the A/S/MEP that directly match the civil design in absolute elevations. Teams with base building design of site adaptation concepts that may occasionally have some projects near coastal regions with a site absolute elevation near 100 feet should pay particular attention to the coordination of the building using the base building in local relative coordinates and the civil site in absolute that appear very similar and can be a source of confusion.

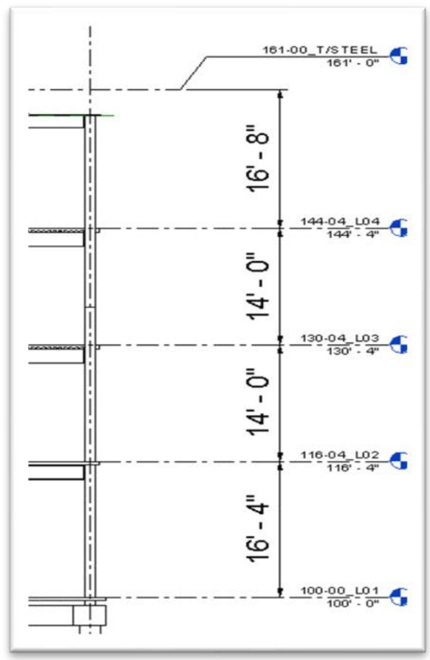

Figure 7: Example Levels in a BxP. The section shows the level of the building relative to finish floor at 100 ft for the local building coordinates.

The practice of architects establishing their local building coordinate elevation at zero (0) feet is strongly discouraged as it creates the condition of the foundation structure to be defined with negative coordinates.

5.2.3. Project (Building) Local - Levels

BIM is typically coordinated by levels over the project, and level definitions are an important subset of the local building coordinates. It is recommended that the project team define this in their BxP/PEP for both design and construction. Typically, each level is defined as the model space from finish floor (FF) of one level to finish floor (FF) of the level above.

5.2.4. *Project (Building) Importance of Structural and Civil Engineers' Input in Grid Line Systems*

A project's structural engineer needs to be able to set the LOD of the origin of the project with the Architect at the end of the DD phase. The entire construction process will begin with the structural engineer's foundation systems and the gridlines shown on the structural design drawings. Unless differences are discovered in the design and modeling process between structural and architectural grid lines, actual architectural content will be formed around the in-place structure that is built. This is an important reason for teams to invest time in verifying that origins and grid systems are confirmed and coordinated in the design models. Additionally, this needs to be coordinated with the civil engineer and site surveyor's state plane coordinates. Following this, manufacturers will reference the Building coordinates for placing their content.

5.3. Campus (Site) Local - Coordinates:

Relative coordinate system of the building's site is defined so that the entire site is in positive point coordinates. This coordinate system will define the Origin and typically have the x-axis defined by the southmost boundary monument and the y-axis defined by the westmost boundary monument. This is so that all points on the local Campus (Site) Coordinates are in the positive ranges of the Cartesian plane.

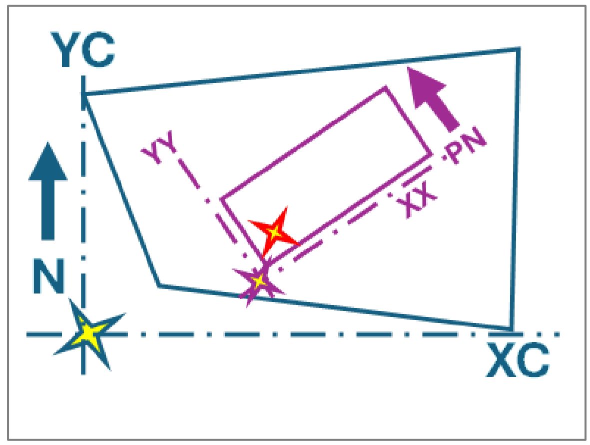

Figure 8: Example of Campus / Site Coordinate. Note the relationship to a local Building (YY-XX) coordinate system with "Plan North" up that is rotated relative to the true North direction of the Campus/Site Coordinate (XC-YC) System. Also note that the location of the Campus coordinates is defined by the South and West most boundary monuments of the surveyed project.

Typically, the relationship to a local Building (YY-XX) coordinate system with "Plan North" up that is rotated relative to the true North direction of the Campus/Site Coordinate (XC-YC) System. Also, the location of the Campus coordinates is defined by the South and West most boundary monuments of the surveyed project. The intersection of YC and XC is defined with a set transform that relates this system to Surface (Ground) Coordinates and the State Plane (Grid) Coordinates. This allows the campus system to be loaded into system typically used by civil engineers without any z-axis rotation and only a X,Y (Northing, Easting) transform. The z-elevation in the Campus (Site) Local Coordinate system is typically set to match the absolute surface elevation from the civil design.

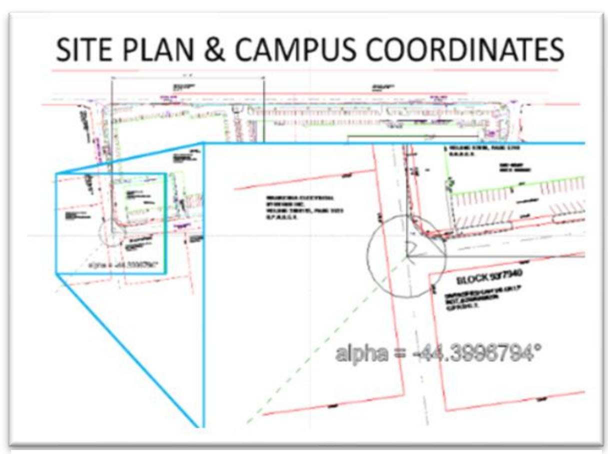

Figure 9: Image show relationship between Surface (Ground) Coordinates, Campus, and local Building coordinates.

5.4. State Plane (Grid) Coordinates:

Absolute coordinate system with Northing and Easting used by surveyors and civil engineers. This is also used by owners tying in their BIM to GIS applications. See section **7 State Plane (Grid) vs Surface (Ground) Coordinates** for further discussion on the relationship between these two coordinate systems. It is important for teams to understand the distinction between these two systems when coordinating building models with civil and survey site content.

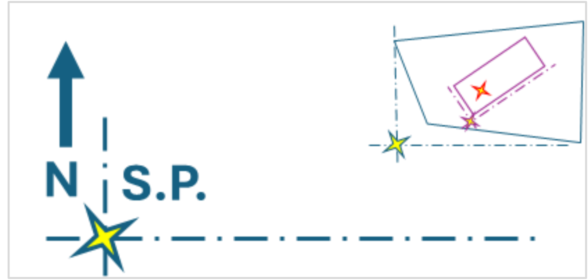

Figure 10: Absolute Northing and Easting coordinate system used in surveying, civil engineering, and BIM–GIS integration

5.5. Surface (Ground) Coordinates:

Coordinate system that accounts for the curvature of the Earth's surface within a localized area. These are project-specific systems where distances are defined and measured on the ground surface. See section **7 State Plane (Grid) vs Surface (Ground) Coordinates** for further discussion on the relationship between these two coordinate systems. It is important for teams to understand the distinction between these two systems when coordinate building models with civil and survey site content. Surface Coordinates are typically what are referenced for indexing reality capture data such as, but not limited to, laser scanning with LiDAR, since the information captured is of content at the surface.

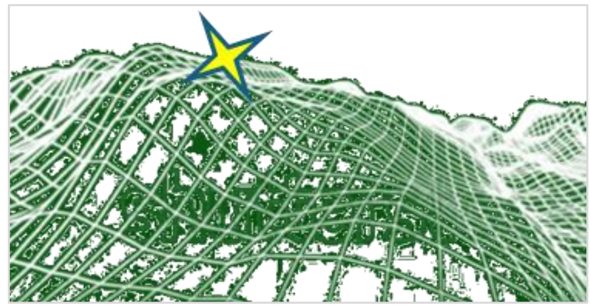

Figure 11: Project-specific coordinate system that accounts for the Earth's surface curvature within a localized area, with distances measured on the ground. Commonly used for coordinating civil and survey data and for indexing reality capture datasets such as LiDAR.

5.6. Global Positioning Satellite (GPS) Coordinates:

Absolute coordinate system with Northing and Easting used by surveyors and civil engineers. This is also used by owners tying in their BIM to GIS applications.

Figure 12: Global absolute coordinate system derived from satellite positioning, widely used in surveying, civil engineering, and BIM–GIS integration workflows.

5.7. Coordinates Summary Table

The following table summarizes the 6 main types of coordinate systems in BIM for VDC.

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COORDINATES
6 KEY SYSTEMS

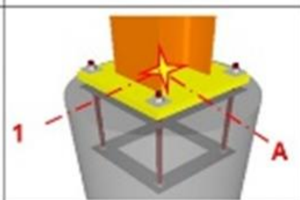
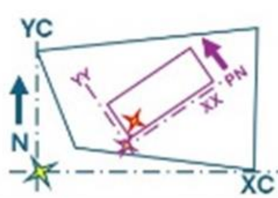
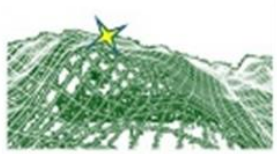
SYSTEM	EXAMPLE	APPLICATION
ELEMENT (OBJECT)		Element Coordinates of Objects & Equipment Relative To Project (Local) Coordinates. Example Of Steel Column With Element Point At Grid A-1 Intersection.
PROJECT (LOCAL)		Project Coordinates (Local) of Building or Structure At Grid 'XX' And 'YY' Typically With A Plan North (PN) Aligned To YY-axis. YY-XX is typically at 0,0 with 10 FT Offset From The Southwest Corner of structure so that all Element coordinates are positive X & Y.
CAMPUS (LOCAL)		Campus Coordinates defined for entire site. Defines relationship of the Project Local System To The Campus System. The YC and XC grids are defined so that the entire property has all elements in the positive coordinate system with YC & XC @ 0,0.
CIVIL PLANE SYSTEM		Plane system (PS) absolute coordinates tied to legal/geodetic systems on a Plane projection (typically a legally defined State Plane) coordinate system to address earth's curvature. Legacy monuments often in us survey ft vs intl. Ft.
CIVIL GROUND /SURFACE		Ground/Surface Coordinates For Surface Measurements Projected Up From The State Plane System. These Are Critical For Indexing Reality Capture Taken At Surface.
GPS		Global Position Satellite Coordinates Which Are Absolutely Coordinates For Geospatial Positioning. These Can Be Directly Correlated With Surface/Ground Coordinates

Figure 13: Overview of the six key coordinate systems used in BIM, illustrating their hierarchy, examples, and typical applications—from element-level local coordinates to global GPS-based systems.

6. Internal Origins Of 3D Models drive Precision, Accuracy and Tolerances

The internal origin is the foundational point of reference within a digital model. The internal coordinate system serves as the local zero point for a single site, building, assembly or component model element. Proper management of the Internal Origin is key to maintaining a clean and efficient model. Its relationship to other project systems and how to manage it effectively to prevent common issues like floating geometry or performance degradation will be explained. Understanding the internal origin is the first step toward mastering a project's spatial data. *The relationship between an element in a model and its internal origin drives the precision, accuracy, and tolerance that can be achieved in 3D model coordination of those elements.*

6.1. Modeling Near the Internal Origin: Best Practices in BIM

Maintaining geometry of constructed elements close to the **Internal Origin (0,0,0)** in Building Information Modeling (BIM) software is important for **model accuracy, performance, and interoperability**. This principle applies across disciplines including architecture, engineering, construction, and geospatial coordination.

Below is a breakdown of the key technical and workflow reasons for adhering to this foundational modeling best practice.

6.2. Floating-Point Precision and Computational Stability

Most 3D modeling software relies on **floating-point arithmetic** to represent spatial coordinates. These floating-point systems are subject to reduced precision as numerical values increase in size or distance from the origin.

Why it matters:

1. Geometry placed far from the origin can suffer from ***rounding errors***.
2. Unreliable snap-to-point tools and alignment functions when objects are far from the internal origin.
3. Small inconsistencies may appear as gaps, overlaps, or jagged edges in otherwise continuous geometry.
4. Visual artifacts such as "shimmering" or “hallucinations” may occur during rendering or navigation.

6.3. Model Performance and File Integrity

Placing geometry far from the internal origin can impact the **efficiency of modeling operations**, particularly in large or complex models.

Issues that may arise:

1. Boolean operations, mesh generation, and rendering become less stable and more error prone.
2. Increased risk of file corruption or model instability.
3. Views and viewports may become sluggish or unresponsive.

4. Some platforms impose a practical working limit on model extents from the origin to avoid these issues.

6.4. Interdisciplinary Coordination and Data Exchange

In multi-model workflows—such as those involving structural, architectural, civil, and fabrication models—project coordinate misalignment can lead to costly errors.

Potential consequences:

1. Models may be important or link with incorrect positioning.
2. Clash detection may yield false positives or miss real interferences.
3. Georeferenced or site-based data may become misaligned when exchanged between teams or platforms.

Best practice:

1. Keep the model's base point, origin, and primary geometry co-located.
2. Use coordinate reference systems (e.g., project base points or survey points) to manage geolocation **without displacing geometry** for constructed elements far from the model origin.
3. For large projects, create separate models with the constructed elements for each model near the internal model origin for each given sub-model.

6.5. Tool Responsiveness and User Interface Reliability

Modeling at significant distances from the Internal Origin can degrade the user experience and reduce the reliability of precision tools.

Observable symptoms:

1. Inaccurate snapping or object placement.
2. Lag in zoom, pan, and orbit operations.
3. Unexpected behavior in dimensioning and annotation.
4. Visual glitches or display errors.

6.6. Summary of Origin Recommendations for Best Practice

AREA OF IMPACT	RISK WHEN MODELING FAR FROM ORIGIN
PRECISION	Rounding errors, alignment issues
PERFORMANCE	Sluggish tools, increased crash risk
COORDINATION	Misaligned links, incorrect placements
USABILITY	Unreliable snapping, view lag

To maintain performance and accuracy:

1. Model close to the Internal Origin for Model Elements which have tighter tolerances for manufacturing, such as but not limited to aluminum curtain wall, structural steel, manufactured equipment, etc.

2. Use external coordinate systems or reference files to represent geographic position but keep the core geometry of constructed elements in sub-models (container models) near the Internal Origin.

3. For large site or infrastructure projects, use position survey or civil data with a transform in the federated model, while preserving proximity of the design model elements near the Internal Origin in building and element models of the given area of constructed model elements. For example, the civil model could show key controlling building grids with Northing and Easting coordinates for two points at grid intersections which would tie the architect's building grids in the building models with the Surface Coordinates in the civil model. The architectural model elements would be created near the Internal Origin of the building model. Manufactured equipment models would also be created near the Internal Origins of those manufactured elements with the locations referenced to the architect's model's Building Grid system grid system that has it relationship with the overall civil model when federated.

4. The general concept is that:

Given Coordinates	**Controlled by Reference to**
Element Coordinate	Project (Building) Coordinates
Project (Building) Coordinates	Campus (Site) Coordinates
Campus (Site) Coordinates	State Plane (Grid) Coordinates Surface (Ground) Coordinates GPS

7. State Plane (Grid) vs Surface (Ground) Coordinates

7.1. Introduction to State Plane (Grid) vs Surface (Ground) Coordinates

Grid coordinates are a two-dimensional system used to locate points on a map projection, representing positions with Northings and Eastings. This system simplifies georeferencing by projecting the curved surface of the Earth onto a flat plane, such as with a UTM (Universal Transverse Mercator) or State Plane coordinate system. The key characteristic of grid coordinates is that they are mathematically consistent within the projection, allowing for straightforward calculations of distance and area. However, this simplification introduces distortions because the Earth's true surface curvature is not accounted for. Consequently, the distance between two points on a map using grid coordinates will not perfectly match the actual distance on the ground.

In contrast, ground coordinates refer to a two-dimensional system that directly measures points on the Earth's actual, curved surface. This system is often used in smaller-scale surveys where local accuracy is paramount, and the effects of Earth's curvature are significant. Ground coordinates are not tied to a specific, standardized map projection and are typically defined by the user for a particular project area. Unlike grid coordinates, ground distances calculated from ground coordinates will be very close to the actual measured distances on the Earth's surface. The main difference lies in how each system handles the Earth's curvature: grid coordinates use a mathematically defined projection to create a flat reference plane, while ground coordinates work directly on the curved surface, leading to more accurate ground-level measurements.

7.2. Correction Factor for State Plane (Grid) to Surface (Ground) Coordinates

In surveying, the correction factor used to convert civil State Plane (grid) Coordinates to Surface (Ground) Coordinates accounts for the fact that State Plane Coordinates are defined on a mathematical projection surface, not on the actual ground where construction occurs.

> *Simply stated:* ***Grid distances ≠ Ground distances****, and the correction factor bridges that difference.*

7.3. Why a Correction Factor is Required

State Plane Coordinate Systems (SPCS) are **map projections**. They:

1. Represent the curved Earth on a flat mathematical surface (the grid)
2. Use a reference ellipsoid and projection (Lambert Conformal Conic or Transverse Mercator)
3. Are optimized to minimize distortion over a defined zone

However, construction occurs on the **physical ground surface**, which is:

1. At a specific elevation above the ellipsoid
2. Subject to scale distortion from the projection
3. Measured with instruments that operate in real space

As a result, a distance measured on the ground will **not exactly match** the distance computed from grid coordinates, hence the need for a correction factor.

7.4. The Two Components of the Correction Factor

The total correction from **grid → ground (surface)** consists of **two multiplicative components**:

7.4.1. (A) Grid Scale Factor (Projection Scale Factor)

This accounts for distortion introduced by the map projection.

- In State Plane systems, the scale factor is:
  - Exactly 1.000000 along designated standard lines
  - Slightly greater or less elsewhere in the zone

Typical magnitude:

- ±20 to ±100 parts per million (ppm)
- About ±0.1 ft per mile, depending on location

This value is defined by the projection mathematics and varies by **position within the zone**.

7.4.2. (B) Elevation Factor

This accounts for the fact that grid distances are defined on the ellipsoid, not at ground elevation.

Formula (conceptual):

$$\text{Elevation Factor} = \frac{R}{R + h}$$

Where:

- (R) = Earth's mean radius (or radius of curvature)
- (h) = elevation above the ellipsoid

Key implications:

4. Higher elevations → larger correction
5. At sea level, the elevation factor ≈ 1.000000
1. At typical building elevations, this can introduce **10–50 ppm**

7.4.3. *(A+B) The Combined Grid-to-Ground Correction Factor*

The **combined correction factor (CF)** is:

$$\boxed{\text{Combined Factor} = \text{Grid Scale Factor} \times \text{Elevation Factor}}$$

where:

1. CF = Combined Correction Factor
2. GSF = Grid Scale Factor
3. EF = Elevation Factor

This factor converts distances:

1. **Grid → Ground**: multiply by CF
   Ground → Grid: divided by CF

7.5. Practical Example

Assume:

1. Grid Scale Factor = 0.999950
2. Elevation Factor = 0.999990

$$\boxed{\text{CF} = 0.999950 \times 0.999990 = 0.999940}$$

If a grid distance is **1,000.000 ft**:

$$\boxed{\text{Ground Distance} = 1{,}000.000 \times 0.999940 = 999.940\ \text{ft}}$$

That is a **0.060 ft (≈ ¾ in)** difference over 1,000 ft.

On large sites or infrastructure projects, this difference becomes **significant**. It is also significant if you perform reality capture with laser scanning on a large project such as an airport terminal with the scans tied (indexed) to survey monuments over 1,000 ft distances. For this example, if the laser scanning tolerances were to be +/- ½" and the monument conversions were not accounted for, it would create an additional ¾" of discrepancy.

7.6. Terminology Used in Practice

You may see this Correction Factor referred to as:

1. Grid-to-Ground Factor
2. Combined Scale Factor
3. Projection + Elevation Correction
4. Ground Scale Factor
5. State Plane Reduction Factor

7.7. Why this Matters for BIM and Construction

In Civil / Surveying

1. Coordinates delivered in State Plane are **State Plane (Grid) Coordinates.**
2. Field layout is Surface (Ground) Coordinates.
3. Without correction, layout errors accumulate

In BIM / VDC

1. BIM models often operate in **Surface (Ground) distances**
2. GIS and civil models operate in **State Plane (Grid) coordinates**
3. Misalignment occurs if the correction factor is not documented

Best Practice

A project should **explicitly state**:

1. Whether coordinates are State Plane (Grid) or Surface (Ground) Coordinates
2. The combined correction factor (CF) used
3. Whether distances shown in models are:
4. Grid distances
5. Ground distances
6. Or transformed between the two

7.8. Summary of Grid & Ground Coordinates:

State Plane Coordinates are grid-based and represent distances on a projected surface. For construction and layout purposes, these distances must be adjusted to ground (surface) distances using a combined grid scale and elevation correction factor (CF). Failure to apply this correction can result in measurable discrepancies between modeled dimensions and field measurements.

The grid-to-ground correction factor reconciles mathematical map projection distances with real-world ground measurements by accounting for projection distortion and elevation above the ellipsoid.

8. Accuracy

Accuracy describes how closely a measured or modeled value corresponds to its true or intended position in the real world. In BIM and VDC workflows, accuracy determines whether spatial information can be trusted for decision-making, coordination, and construction. An element may be represented with many numeric digits, but if it is not located where it is intended to be relative to the project coordinate system, it is inaccurate. Accuracy is therefore concerned with correctness of location, orientation, and size, and must be evaluated relative to the project's defined coordinate framework and intended use.

9. Precision

Precision describes the level of numeric detail and repeatability with which measurements or coordinates are expressed, independent of whether they are correct. Modern BIM applications allow elements to be modeled with extremely high precision, often many decimal places beyond what is physically meaningful or constructible. A model element may be precisely defined to fifteen decimal places yet be located meters or miles from its intended position, rendering it unsuitable for coordination despite its apparent exactness. Precision is a property of representation, not truth, and must be intentionally managed so that it aligns with the needs of coordination rather than software defaults.

As we look at the different disciplines, customary units are observed with the given professions such as civil engineers using decimal feet to 2 decimal places while architects will show feet and inch fractions rounded to the nearest 1/8" or ¼" in most cases, while aluminum curtain die extrusion drawing my show inches to 3 or 4 decimal places on fabrication drawings. Each profession's typical units and the precision used normally correlate to the accuracy and tolerance of manufacturing, fabrication, erection and construction. The challenge this guide addresses is when these different professions and building interfaces need to be coordinated.

10. Units

> ***"You can't manage what you don't measure."***
> ***Peter Drucker***

10.1. A Tale of Two Feet: U.S. Survey Feet and International Feet

A common point of confusion, especially of projects in the U.S., is the subtle yet significant difference between the U.S. Survey Foot and the International Foot. This distinction is a prime example of why precision and clarity are important from the very start of a project.

The Metric Law of 1866 defined the US Survey Foot by stating that one meter equals 39.37 inches.[1] Specifically, it was defined as exactly 1200/3937 of a meter, yielding an approximate value of 0.3048006096 meters. This definition was intrinsically linked to the U.S. National Spatial Reference System (NSRS) and was the foundational unit for State Plane Coordinate systems and other land measurement activities within the U.S. for over a century. Its continued use was largely predicated on the extensive body of existing survey data and legal documentation reliant on this specific relationship to the meter.

Conversely, the international foot was adopted in 1959 and aimed to standardize the foot for industrial, commercial, and general scientific applications. The international foot was precisely defined as 0.3048 meters. This standardization provided another alternate measurement standard for global trade and technological exchange, effectively harmonizing a unit that had previously exhibited slight national variations.

The fundamental difference between the U.S. survey foot and the international foot lies in their precise conversions to the meter. The international foot is exactly 0.3048 meters, whereas the U.S. survey foot is approximately 0.3048006096 meters. This results in the U.S. survey foot being longer than the international foot by approximately 2 parts per million. While this disparity is negligible for most everyday applications, its cumulative effect over vast distances can lead to substantial errors in high-precision geodetic measurements. For instance, over a distance of 100 miles, the discrepancy accumulates to approximately 1.056 feet. Such an error is critical in fields like surveying, large-scale infrastructure projects, and the establishment of national coordinate systems where positional accuracy is paramount.

Historically, the coexistence of these two definitions presented a challenge to metrological consistency within the United States. To mitigate the potential for confusion and error, and to align U.S. measurement practices with international standards, the National Institute of Standards and Technology (NIST) and the National Oceanic and Atmospheric Administration (NOAA) officially retired the U.S. survey foot, effective December 31, 2022. This decision mandates that all future federal related measurements and surveying activities within the United States will exclusively utilize the international foot (henceforth simply "the foot"), coinciding with the comprehensive modernization of the NSRS that is currently

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[1] Heidi Whitver, *US Survey Foot vs. International Foot: How and When to Utilize Each*, HR GREEN, INC. (June 23, 2023), https://www.hrgreen.com/us-survey-foot-vs-international-foot/.

undergoing phased roll-out and testing through 2026.[2] This transition marks a significant step towards greater metrological uniformity and precision in geospatial data.

However, for the US building industry there are over a century of existing building sites and survey monuments documented in the US Survey Foot. Some projects may have their state plane origins more than seven million feet from the building which would result in over a fourteen-foot difference between the two units. An mock example project is shown in **Section 15 Exhibit 'A': Mock Example of Lone** Star Airport which is a hypothetical airport built in the 1970's with historic data in US Survey Foot that is undergoing a modern modular expansion in 2030 in international foot units. The mock example shows the types of problems that can arise when teams require reality capture data to be provided "on the Owner's monuments" without a clear definition of which foot is referenced. Some municipalities and entities at the time of writing (2025) still use the US Survey Foot. For example, if an architect's model is based on international feet, while the civil model, by jurisdiction, is based on US Survey Feet for monumentation, discrepancies can occur when reality capture is tied to those survey monuments for architectural model coordination. The issues of unit transforms can be resolved with relative ease given clear communication and careful, consistent model transforms. However, the issue of unit discrepancies can be significant if such communications do not occur early in a project before substantial time and effort is invested into modeling.

[2] Visit the NGS Beta site for the latest developments at https://beta.ngs.noaa.gov/ and refer to the NGS News release for further info at https://geodesy.noaa.gov/web/news/pdf/BETA-release-6-17-25.pdf

10.1.1. *US Survey & International Foot Table*

The table below shows relationships for Units of Measure Based on the Foot, Including Exact Conversions to Meters for the International Foot and Approximate Conversions to Meters for the U.S. Survey Foot,[3] Guide for the Use of the International System of Units (SI). Except for the *"Mile and Square Mile, these units were previously only defined with the U.S. Survey Foot."* The table below is from 62698 Federal Register / Vol. 85, No. 193 / Monday, October 5, 2020 / Notices,[4] and addresses NIST's depreciation of the US Survey Foot.

Table 1: Exact Relationships for Units of Measure Based on the Foot, Including Exact Conversions to Meters for the International Foot and Approximate Conversions to Meters for the U.S. Survey Foot

Units based on the foot	Unit type	Exact U.S. customary definitions based on the foot, plus other exact definitions	International foot metric equivalent (exact)	U.S. survey foot metric equivalent (approximate)
foot (ft)	**length**	**Defined with respect to meter**	**0.304 800 000 000 m**	**0.304 800 609 601 m**
cable's length	length	720 ft = 120 fathoms	219.456 m	219.456 438 913 m
chain (ch)	length	66 ft = 4 rd = 100 li	20.1168 m	20.116 840 234 m
fathom	length	6 ft	1.8288 m	1.828 803 658 m
furlong (fur)	length	660 ft = 10 ch = 40 rd	201.168 m	201.168 402 337 m
league	length	15,840 ft = 3 mi	4828.032 m	4828.041 656 083 m
link (li)	length	0.66 ft = 0.01 ch	0.201 168 m	0.201 168 402 m
mile (mi) [(a)]	length	5280 ft = 8 fur = 80 ch = 320 rd	1609.344 m	1609.347 218 694 m
rod (rd), pole, perch	length	16.5 ft = 0.25 ch	5.0292 m	5.029 210 058 m
acre (ac)	area	43,560 ft^2 = 10 ch^2 = 160 rd^2	4046.856 422 4 m^2	4046.872 609 874 m^2
square mile (mi^2)	area	27,878,400 ft^2 = 640 ac	2 589 988.110 336 m^2	2 589 998.470 319 521 m^2
acre-foot	volume	43,560 ft^3	1233.481 837 547 52 m^3	1233.489 238 468 149 m^3

(a) Also referred to as the "statute mile." on the U.S. survey foot should be avoided after December 31, 2022, except for historic and legacy applications.

[3] *NIST Guide to the SI, Appendix B: Conversion Factors*, NIST (2016), https://www.nist.gov/pml/special-publication-811/nist-guide-si-appendix-b-conversion-factors.
[4] NIST, *Federal Register :: Deprecation of the United States (U.S.) Survey Foot*, FEDERAL REGISTER (Oct. 5, 2020), https://www.federalregister.gov/documents/2020/10/05/2020-21902/deprecation-of-the-united-states-us-survey-foot; *U.S. Survey Foot*, NIST (2019), https://www.nist.gov/pml/us-surveyfoot.

10.2. Units, Other

The BIM sections of project execution plans should clearly define the units and precision for the intended purpose of the project. The following table shows a summary of the type of units that would be used for a project in the US.

Building System / Discipline	Typical Linear Units	Typical Area Units	Typical Volume Units	Notes on Practice
Architectural – Overall Building Layout	Feet (ft), Inches (in)	Square Feet (SF)	Cubic Feet (CF)	Floor plans, grids, levels, and room layouts typically expressed in ft–in.
Architectural – Interior Fit-Out	Inches (in), Fractions	Square Feet (SF)		Millwork, partitions, ceilings, and finishes rely on inch-based precision.
Structural – Concrete	Feet (ft), Inches (in)	Square Feet (SF)	Cubic Yards (CY), Cubic Feet (CF)	Slabs and foundations dimensioned in ft–in; quantities typically in cubic yards.
Structural – Structural Steel	Inches (in), Feet (ft)			Member sizes, connections, and shop drawings are inch-based with tight tolerances.
Structural – Steel Joists & Deck	Inches (in), Feet (ft)	Square Feet (SF)		Joist spacing in feet; profiles and depths in inches.
Civil – Site Geometry	Feet (ft)	Square Feet (SF), Acres (ac)	Cubic Yards (CY)	Coordinates may be large-magnitude; consistency with survey units is critical.
Civil – Roadways & Utilities	Feet (ft)	Square Feet (SF)	Cubic Yards (CY)	Alignments and profiles rely on linear feet; earthwork in cubic yards.
Survey / Geospatial Control	Feet (ft) (International or U.S. Survey)			Must explicitly state which foot; often tied to State Plane systems.
Mechanical (HVAC)	Inches (in), Feet (ft)	Square Feet (SF)	Cubic Feet (CF)	Duct sizes in inches; airflow calculations introduce derived units.
Plumbing	Inches (in)		Gallons (gal), Cubic Feet (CF)	Pipe diameters in inches; capacity and flow use volumetric units.
Fire Protection	Inches (in)		Gallons (gal)	Piping in inches; hydraulics introduce flow-based measures.
Electrical – Power & Lighting	Inches (in), Feet (ft)	Square Feet (SF)		Clearances and mounting heights are geometric; loads are non-geometric.
Low Voltage / Technology	Inches (in), Feet (ft)			Pathways, device mounting, and rack layouts are inch-based.
Façade / Envelope Systems	Inches (in)	Square Feet (SF)		Panels and envelope systems often require tight inch-based tolerances.
Landscape Architecture	Feet (ft)	Square Feet (SF), Acres (ac)	Cubic Yards (CY)	Grading and planting areas align with civil units.

Figure 14: Table of units for typical building systems for projects in the US.

Table of units for typical building systems for projects in SI units' systems.

Building System / Discipline	Typical Linear Units (SI)	Typical Area Units (SI)	Typical Volume Units (SI)	Notes on Practice
Architectural – Overall Building Layout	Meters (m)	Square Meters (m^2)	Cubic Meters (m^3)	Overall layouts, grids, and levels typically expressed in meters.
Architectural – Interior Fit-Out	Millimeters (mm)	Square Meters (m^2)		Interior elements and finishes rely on millimeter-level precision.
Structural – Concrete	Millimeters (mm), Meters (m)	Square Meters (m^2)	Cubic Meters (m^3)	Member dimensions in mm; quantities typically in cubic meters.
Structural – Structural Steel	Millimeters (mm)			Member sizes, profiles, and connections are millimeter-based.
Structural – Steel Joists & Deck	Millimeters (mm), Meters (m)	Square Meters (m^2)		Spacing in meters; depths and profiles in millimeters.
Civil – Site Geometry	Meters (m)	Square Meters (m^2), Hectares (ha)	Cubic Meters (m^3)	Large-scale geometry typically uses meters; land areas may use hectares.
Civil – Roadways & Utilities	Meters (m)	Square Meters (m^2)	Cubic Meters (m^3)	Alignments, profiles, and earthwork standardized in meters and cubic meters.
Survey / Geospatial Control	Meters (m)			Geodetic and national coordinate systems are meter-based.
Mechanical (HVAC)	Millimeters (mm)	Square Meters (m^2)	Cubic Meters (m^3)	Duct sizes in mm; airflow introduces derived units (e.g., m^3/s).
Plumbing	Millimeters (mm)		Cubic Meters (m^3)	Pipe diameters in mm; storage and capacity often in cubic meters or liters.
Fire Protection	Millimeters (mm)		Cubic Meters (m^3)	Pipework and system geometry in mm; flow adds derived units.
Electrical – Power & Lighting	Millimeters (mm), Meters (m)	Square Meters (m^2)		Clearances and mounting heights defined geometrically in mm.
Low Voltage / Technology	Millimeters (mm), Meters (m)			Pathways and device layouts typically modeled in millimeters.
Façade / Envelope Systems	Millimeters (mm)	Square Meters (m^2)		Panel systems require millimeter-level geometric control.
Landscape Architecture	Meters (m)	Square Meters (m^2), Hectares (ha)	Cubic Meters (m^3)	Grading and planting areas align with civil SI conventions.

Figure 15: Table of units for typical building systems for projects in SI units' systems.

11. Tolerances

11.1. Tolerance Introduction

It is normally the design team's responsibility to cite the standard and specification tolerances for the design. This is achieved by details and specifications in the construction documents that alert the field team of the tolerances permitted for each of the construction elements. For example, in the case of a reinforced concrete building frame or precast/prestressed concrete in the U.S., the maximum tolerances permitted should be those listed in the American Concrete Institute (ACI) *117 Concrete Tolerances Specification & Commentary.*[5] Alternately, tolerances for structural steel building frames should be specified per the referenced version of ANSI/AISC 303: Code of Standard Practice.[6] For masonry, The Masonry Society's (TMS) 402/602 Building Code Requirements and Specification for Masonry Structures contains two standards and their commentaries: Building Code Requirements for Masonry Structures (TMS 402) and Specification for Masonry Structures (TMS 602). The Code (TMS 402) covers the design and construction of masonry structures while the Specification (TMS 602) is concerned with minimum construction requirements for masonry in structures.[7] Both of these masonry documents provide tolerance information for design and construction of masonry. For perspective, Table 2 below is intended to show a sample of typical tolerance ranges across building materials. The table is not intended as a design or construction reference. The table illustrates the types of variations in tolerance across the materials of model elements. Teams should consider the tolerances of the given coordinate system for the intended purpose of coordination. While an exhaustive review of tolerances is beyond the scope of this coordinate guide, examples of use cases are given in this section for reference, providing background for teams to address the topic of tolerance with the project's trade partners.

[5] ACI, SPECIFICATIONS FOR TOLERANCES FOR CONCRETE CONSTRUCTION AND MATERIALS (ACI 117-10) AND COMMENTARY (2010 ed. 2010).
[6] AISC, AISC 303: CODE OF STANDARD PRACTICE FOR STEEL BUILDINGS AND BRIDGES (2022 ed.), https://www.aisc.org/globalassets/aisc/publications/standards/a303-22w.pdf.
[7] TMS, *TMS 402/602-22 Building Code Requirements and Specification for Masonry Structures*, (2022), https://masonrysociety.org/tms402/.

11.2. Sample Table of Representative Tolerances

Table 2: Sample Table of Representative Tolerance Variation for A Limits Sample of Building Element Examples.

SAMPLE Material	SAMPLE Industry Standards / Specifications	SAMPLE Representative Tolerances (Summary)
Building Layout and Sitework	ISO 4463-1 *Measurement Methods for Buildings*. NATIONAL SOCIETY OF PROFESSIONAL SURVEYORS (NSPS) *Model Standards for Construction Layout Surveys*	±1/8 in. (3 mm) per 100 ft for laser layout; ±1/4 in. (6 mm) for tape layout; ±1/2 in. (13 mm) max on long axes.
Concrete	ACI 117 *Specifications for Tolerances for Concrete Construction*; PCI MNL-135 *Precast/Prestressed Concrete Construction*	Slabs ±1/4 in. in 10 ft; precast beams length ±1 in.; pilings +1 in. (25 mm), −2 in. (50 mm).
Steel	AISC 303 *Code of Standard Practice for Steel Buildings and Bridges*; ASTM A6/A6M *General Requirements for Rolled Steel*	Out-of-plumb columns 1:500; member length ±1/8 in. per 10 ft; camber/sweep within 1/2 of standard tolerances.
Unit Masonry	ACI 530.1 / ASCE 6 / TMS 602 *Specifications for Masonry Structures*; ASTM C90, C129, C901	Wall alignment ±1/4 in. in 10 ft; joints ±1/8 in.; unit size ±1/8 in. (3.2 mm); prefabricated panels ±1/4 in. (6 mm).
Stone	MIA *Dimension Stone Design Manual VI*; Indiana Limestone Handbook; Cast Stone Institute 04 72 00	Fabrication: ±1/16 in. (1.5 mm); plumb ±1/4 in. in 10 ft; wall alignment ±1/2 in. per story; cast stone L/360 or ±1/8 in.
Structural Lumber	National Design Specification (NDS); NLGA Standard Grading Rules	Length ±1/8 in.; straightness 1/4 in. in 10 ft; moisture shrinkage allowances per NDS.
Finish Carpentry & Architectural Woodwork	AWI / AWMAC / WI *Architectural Woodwork Standards*	Millwork joints ±1/32 in.; face alignment ±1/64 in.; cabinet alignment ±1/16 in. in 10 ft.
Curtain Walls	AAMA CW-10; ASTM E2112 *Installation of Exterior Windows & Doors*	Frame plumb ±1/8 in. in 12 ft; glass edge clearance ±1/16 in.; joint width ±1/8 in.
Finishes	SPECTEXT 09546 *Metal Linear Ceilings*; CISCA *Ceiling Systems Handbook*	Ceiling flatness ±1/8 in. in 10 ft; grid position ±1/4 in.; wall finish variation ±1/8 in. over 8 ft.
Glazing	ASTM C1048 *Flat Glass – Heat-Treated, Tempered, Laminated*; GANA Glazing Manual	Flat glass size ±1/16 in.; bow ≤0.3% of length; insulated glass squareness ±1/8 in.
Doors & Windows	ANSI A250.8 *Steel Door and Frame Installation*;	Frame plumb ±1/16 in.; head alignment ±1/8 in.; gap uniformity ±1/16 in.; twist ≤1/8 in. across width.

11.3. Variations in Tolerances: Movement, Thermal Expansion/Contraction, Joints, Fire Proofing, Material Variation, etc.

A related topic to tolerances of building assemblies and components is movement such as, but not limited to, live load deflections, wind displacements, seismic drift, and thermal expansion and contraction. An exhaustive discussion of building movement is beyond the scope of this guide on coordinates. However, it is noted for the reader to consider as it relates to detailed coordination of built content represented with Model Elements in BIM. A list of examples to consider include but are not limited to the following:

11.3.1. Curtain Wall Elements:

Curtain Wall systems, which are primarily glass and aluminum, have notable thermal expansion and contraction considerations. These conditions are more significant with longer spans of aluminum elements on the exterior of the building, especially in regions with large seasonal temperature variations. The curtain wall attachments are often comprised of (1) one *combined gravity and lateral* load connection on the mullion element, and (2) one or more other *lateral only* connections for wind and seismic loads. These connection configurations allow the curtain wall system to 'breath' with thermal expansions and contractions over its vertical length by having only one gravity connection on the mullion to constrain vertical movement. Additionally, there are often movement joints between floor levels which, among other reasons, account for live load deflection, structural compression, creep and shrinkage, differential deadload deflection, and other structural differential movements over time. The final in-place state of the modeled elements need to account for sufficient clearance spaces for the thermal expansion of the curtain wall system as well as the differential floor live load movement and lateral building frame movement from wind and seismic forces.

11.3.2. Fire Proofing over Structural Steel:

Structural fire proofing thicknesses are often varied over structural steel based on the thickness of the structural steel Model Elements and fire rating requirements. This can represent a challenge in model coordination and the location of controlling geometries for model coordination. Many teams often use the conflict tolerance feature of coordination software to address the thicknesses of fire proofing in lieu of modeling the fire proofing on the steel.

11.3.3. Long Span Transfer Girders Supporting Multiple Floors above:

Transfer girders occur in structures where columns do not go down directly to a foundation. The challenge with movement and deflection of these systems, particularly in steel, is that the initial construction state includes the girder element cambered up. In cases of multiple levels above, the deflection of the system will change as each level is constructed. Often, the modeled elements are positioned in their final constructed states. Construction coordination of these conditions requires that considerations be made for the sequential construction deflections.

11.3.4. Long Span Composite Steel Beams:

Composite steel beams exhibit construction movement with camber similar to long-span transfer girders, though to a lesser extent.

11.3.5. Interfaces of Long Spans/Heights of Dissimilar Systems:

Conditions of long spans of building elements which are of dissimilar systems represent a challenge for coordination. These could include examples of tall curtain wall systems cited above that are interfacing with concrete or masonry systems. These joint coordination challenges are further exacerbated under conditions of notable wind loads or seismic lateral drift. Designers should consider these tolerance aspects of system selection when they are designing their joint details.

11.4. Civil Subgrade Connection to Landscape, A, S and MEP

Tolerance issues need to be discussed and agreed on with teams in relation to civil subgrade content coordination with architectural, structural and MEP. Landscape architecture also typically has elements with varying tolerances over the life the landscape elements. Typical areas of coordination challenges can be tree planter raised beds over elevated structural plazas, for example. Such conditions require communication early on for element tolerances across the different system interfaces between architecture, landscape, structure and MEP systems.

11.5. Design Grids

Grids in Construction Documents are important for documenting and memorializing the geometry of the built environment. Grids represent a powerful coordination tool *IF the whole design team uses them* between all of the design disciplines which include, but are not limited to, architecture, structure, mechanical, electrical, and plumbing. It is informative to note how the different design teams cite the grid systems of the building in each of their respective disciplines when a set of construction documents (CD) are reviewed. Design reviews are improved when all of the design team members show the exact same grid systems on their respective plans in the published CD's issued for building permits. These grids should be published from the coordinated BIM used in design and noted when any design discipline's CDs do not display grid lines on the plan sheets. It can be an early indication that the teams have not done detailed design intent coordination for constructability. Some designers feel that they ostensibly reduce the chances of being liable for design errors if they do not show grid lines. Others have relied on referring to all detailed coordination as ways and means of construction and that their drawings should only indicate a design intent. Such firms typically do not create BIM with model elements beyond approximate locations (see section 12 LOD for LOD 200, approximate). In this case, it is helpful for builders to verify the design BIM that are shared with them by the project owner, as the model elements may not be in specific locations (see section 12 LOD for LOD 300, specific location). However, in the age of BIM, grids are a critical tool in documenting the origin of the model and the relationship of model elements to that origin and each other. At the time of writing, the BIMForum Global LOD specification is the only such document that defines LOD for points, lines, and grid lines, specifically. It is the position of this guide that if the intent is for Model Elements in a BIM to be at specific location, then the grids they are referenced from, and which appear in the Contract Documents issued for bid, permit or construction, should also be specifically modeled in the correct location relative to the origin of the model. This defined position of the grids relative to the project origins should also be documented in the Contract Documents, especially if the project requires the trade partners to model their content for detailed coordination and fabrication in BIM (see section 12 LOD for LOD 350 & 400, respectively).

11.6. Construction Lines and Points in Design BIM and Contract Documents

With integrated teams in delivery methods such as Design Build (DB), Design Assist (DA), and Integrated Project Delivery (IPD) for example, it can be helpful to incorporate the construction team's input on construction lines they would utilize on site in relation to the design grids. Ideally, by the end of design, the design teams would include key construction layout grids and control points in the design model relative to the project's origin and design grid system. This is normally not realistic in Design-Bid-Build (DBB) delivery methods but can aid in coordination from design to construction on integrated projects where the teams can more easily collaborate with each other during design finalization and pre-construction.

11.7. Grids with Curved Geometry

Project designs with curved geometry should identify a clear Working Point (WP) for the center of the arc. They should also document the radius of the curve, start point of tangent, end point of tangent, and angular sweep of the arc. The WP should be referenced to the design grids and the Project Origin. The goal is to document and memorialize the geometry from the BIM that are required to express the design intent in the Construction Documents (CD) issued for permit, which typically become part of the legal documents for construction. In projects where there are multiple radial grids converging near a common working point, designers should take care to model the points accurately with snapping tools so there are no multiple WPs for radial grids that are fractions of an inch from each other when the radii are hundreds of feet long.[8] There is typically not a sufficient reason for designers to model grid systems inaccurately with rounding errors given modern modeling tools and content that is within a reasonable distance from the internal origin of the software for the tolerances required. From the case studies reviewed for this guide, the issues with design grid systems is not a function of limitation in the technology of BIM software applications themselves, but rather the designers 'using' (or miss-using) the BIM.

11.7.1. Angular Precision

Angular precision becomes a factor with curved geometrical conditions, whether related to whole elements such as curved facades, or the layout of individual elements as a curved array. Angles that are documented in the printed Construction Documents for building permits with the minimum required number of significant figures for the given tolerance of elements being documented help keep errors under control. Consider a pair of concrete columns on radial grids that are laid out at the intersections of a circumferential grid and radial grids. The two columns are 24"x24" and are separated by a 2" expansion

[8] In project case studies reviewed for this guide, multiple project examples were received where the architect had designs with curved geometry. In many cases, the architect had modeled the systems approximately with as many as 12 Working Points that were within 2.375" (2-3/8") from each other over 800 feet away from the columns they were documenting. When this was pointed out, the architect agreed that the differences would materially affect the aesthetics of the building, but did not want to update their model or construction drawings. The models were shared to the construction team with a typical electronic release document that removed liability for the designer modeling practices. After multiple Requests For Information (RFIs), it was determined that it was best to completely rebuild the project grid system with grids laid out at specific locations in the model (LOD 300) and send the resulting dimensional control sheet as a confirming RFI to the design team. This process took notable time and effort that could have been mitigated if the architect had better control of its modeling practices with grids in BIM.

joint. The corners for the columns have a standard ¾” chamfer. For this example, the circumferential grids are established at a radius of 800 feet from a working point. The following would be the angular precision that the design team should show in its construction documents. The column formwork would have a tolerance of +/- 1/8”. A good rule of thumb is to set the tolerance of precision as half the direction that is being held. In this case, 1/16”. Thus, the design drawings should show the angular degrees to four decimal places (+/- 0.00005) IF the design team intends to show its design intent for concrete geometry to American Concrete Institute (ACI) tolerances. In practice form the case studies reviewed for this guide, the time it takes to accurately model design geometry, particularly angular geometry, is far less than the time designers will spend answering Request For Information (RFI) (or construction litigation) when their design geometry in the Contract Documents does not ‘close’ or ‘add up’.

L = 800.00 ft

Gap = 1/16” (0.00521 ft)

Angle = 0.000373 degrees

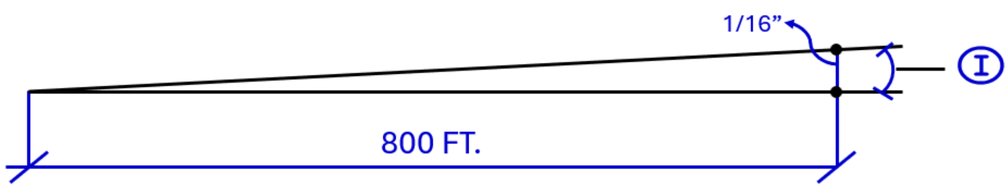


Figure 16: Illustration showing how small angular deviations over a long radius (800 ft) translate into measurable linear offsets. This example highlights the need to document angular values with sufficient precision in construction documents to maintain element tolerances when working with curved or radial geometry.

12. LOD

Level of Detail (LOD) and Level of Development (LOD) are beyond the scope of this guide. LOD is a scale that memorializes and communicates the level of reliability of the information communicated by the model element in a BIM. The most important aspect of coordinates as it relates to LOD is that for an element to be at LOD 300, it must be specific for ALL of the following characteristics of the element: (1) Quantity, (2) Size, (3) Shape, *(4) Location, AND (5) Orientation*. The model's coordinate system must be ***specified*** if the Model Elements it contains are to be "*specific"* for location and orientation.

New to the 2025 version is the LOD 250 definition that specifically addresses tolerance in BIM on VDC projects for 'approximate' model elements that have predictable geometry within a given tolerance but falls short of the 'specific' requirement of LOD 300.

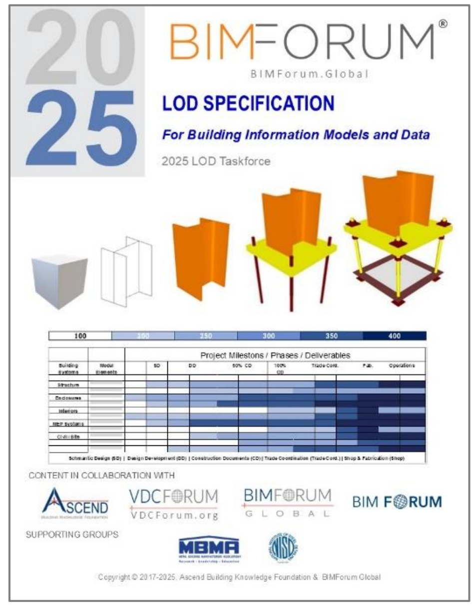


Figure 17: Cover of the BIMForum 2025 LOD Specification. LOD defines the reliability of information contained in a BIM element.

LOD 100-400 Definition

The table below provides a summary of BIMForum Global LOD 2025 Specification:

BIMForum.Global LOD Specification
Version: 2025

BIMForum.Global LOD Definitions

The following are applications of the BIMForum Global Ten Fundamental LOD (Recommended) 'Rules' using the original steel column example. Non-Graphical Information is addressed in BFG LOD Rule #6 "**Model Element (ME) Information Requirements Must be Defined in the BIM PEP"**. Each project team should establish the LOD definitions used for a given project in the Contacts and BIM sections of its PEP. In the absence of such a definition, the following LOD definitions shall apply when this Specification is adopted by reference.

LOD 100-400 Definitions

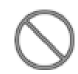
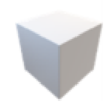
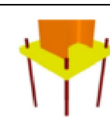
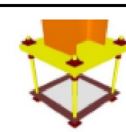
LOD	Summary Concept	Element Accurately Measured from Model at given LOD & LOD 500	Sample Definition	Sample Image
000	**NO BIM**	**N/A**	No distinct Model Elements (MEs) exist, ***AND*** No inference can be made from an overall mass for these elements at this LOD in this system.	
100	**CONCEPTUAL / INFERRED**	**NO** (No Element Exists at this LOD)	No distinct model elements exist but inference about elements can be made from an overall mass at this LOD. The Model Element (ME) may be inferred or referenced in the model with a symbol or other generic representation, but the ME does not satisfy the requirements for LOD 200.	
200	**APPROXIMATE**	**NO** (ME only Approx.)	The Model Element (ME) is modeled **approximately** in terms of one or more of the following characteristics: quantity, size, shape, location, ***OR*** orientation.	
250	**PREDICTABLE within a set TOLERANCE**	**ONLY WITHIN A DEFINED TOLERANCE, +/- 2" (2.56 cm) UNO**	The Model Element (ME) is modeled **approximately** in terms of size, shape, location, ***and*** orientation. The quantity of the ME is specific. The ME perimeter surface and interfaces with other elements are modeled within a defined tolerance of +/- 2", Unless Noted Otherwise (UNO).	Same as LOD 200 within a set tollerance
300	**SPECIFIC**	**YES** within ME Project / System Tolerances	The Model Element is modeled **specifically** within the project's tolerances for its system in terms of ***ALL*** of the following characteristics: quantity, size, shape, location, ***AND*** orientation.	
350	**DETAILED COORDINATION**	**YES** within ME Project / System Tolerances	The Model Element (ME) is modeled specifically per LOD 300 ***AND*** **includes interfacing features** with adjacent and/or dependent model elements to facilitate detailed coordination between systems.	
400	**FABRICATE**	**YES** within ME Project / System Tolerances	The Model Element (ME) is modeled with details required for fabrication, manufacturing, assembly and installation.	

Figure 18: Table from the BIMForum Global LOD Specification (2025) summarizing Levels of Development from LOD 100 through LOD 400, and the increasing specificity required for model elements. New in this version, is the LOD 250 definition that specifically addresses <u>*tolerance*</u> *in BIM on VDC projects for 'approximate' model elements that have predictable geometry within a given tolerance but falls short of the 'specific' requirement of LOD 300.*

13. Reality Capture & Site Documentation

Reality capture, photogrammetry, laser scanning with Light Detection and Ranging (LiDAR) are beyond the main scope of this guide on Coordinates.

It is important to consider the discussion on survey coordinates if a project involves reality capture over a large area with tight tolerances, see section **7 State Plane (Grid) vs Surface (Ground) Coordinates** for further discussion on the relationship between these two coordinate systems. for further discussion on the relationship between these two coordinate systems). It is also significant if you perform reality capture with laser scanning on a large project such as an airport terminal with the scans tied (indexed) to survey monuments over 1,000 foot distances. For this example, if the laser scanning tolerances were to be +/- ½" and the monument conversions were not accounted for, it would create an additional ¾" discrepancy.

For a more in-depth discussion of reality capture, visit https://bimforum.global/reality/ for the Level Of Acceptance (LOA) specification.

Figure 19: Cover of the VDCForum 2025 Level of Acceptance (LOA) Specification, which defines requirements for BIM reality capture and simulation, including laser scanning, LiDAR, and related technologies used in project execution.

14. Conclusion

Clear **C**oordinates, **A**ccuracy, **P**recision, **U**nits, and **T**olerances (CAPUT) definitions are fundamental to the success of any Virtual Design & Construction (VDC) project with Building Information Modeling (BIM). It is the position of this guide that without a clear definition of project coordinate system with all the elements of CAPUT, every measurement is a guess, and no model elements are beyond approximate for orientation and location. The major aspects of a coordinate system are [1] Coordinates (C), [2] Accuracy (A), [3] Precision (P), [4] Units (U), and [5] Tolerances (T). Coordination requires communication of the coordinate system to all stakeholders. It is important for teams to remember that coordinate systems define geometry, geometry creates data, and the data is what drives decision on all of the major drivers in the built environment which include but are not limited to safety, cost, time and quality. In conclusion, "*Coordinates, then Coordination"* and beyond to meaningful data that can be used to make important informed decision about projects.

15. Exhibit ‘A’: Mock Example of Lone Star Airport

This is a hypothetical mock example project for educational purposes only titled “Lone Star Airport”. In this example, the Project is 7M ft from State Plane Grid (US Survey). This example assumes:

An original steel and concrete airport terminal built in 1970 located somewhere in North Texas. Terminal #3 of the 6 terminals is to be renovated with a new modern concourse level. It has multi-bad levels that begin with a ground level (L1) where the baggage handling is placed below the concourse level on the 2nd floor (L2). There are also mezzanines and third floors (l3) with a roof above them (L4). There is also a raised rail system that is above the roof level with a monorail train that connects all the 6 terminals.

The structural steel support columns which are nominally W12 wide flange sections on the ground floor are encased in concrete for an outside dimension of concrete that is 1.5 ft x 2 ft.

The challenge of this mock project is to locate the as-built grid system suitable for the structural steel design of the concourse level that will use about half of the existing columns and remove the other half of the existing columns above the concourse level.

15.1. Mock Example Lone Star Airport: Regional Location defining State Plane Grid System.

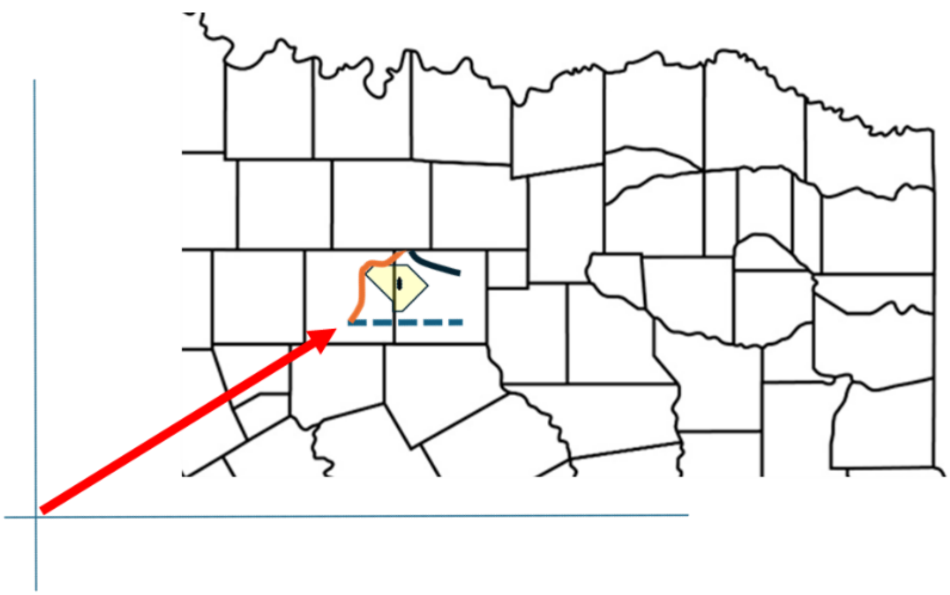


Figure 20: Lone Star Airport, Mock Example: Regional Location defining State Plane Grid System. The Campus coordinate is located with a Northing, Easting of 2.5M US Survey Feet, 7.0 M US Survey Feet.

15.2. Mock Example Lone Start Airport: Enlarged Campus plan

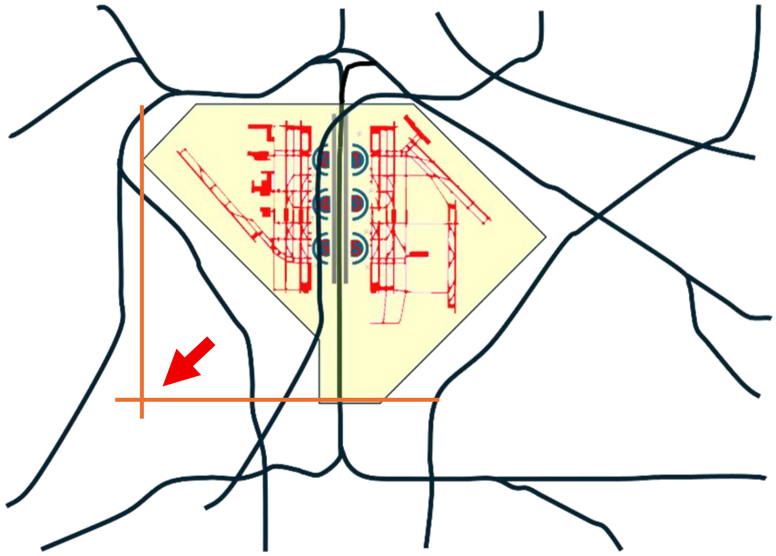


Figure 21: ***Lone Start Airport, Mock Example:*** *Enlarged Campus plan showing local Campus Coordinate System for the approximately 60 square mile campus.*

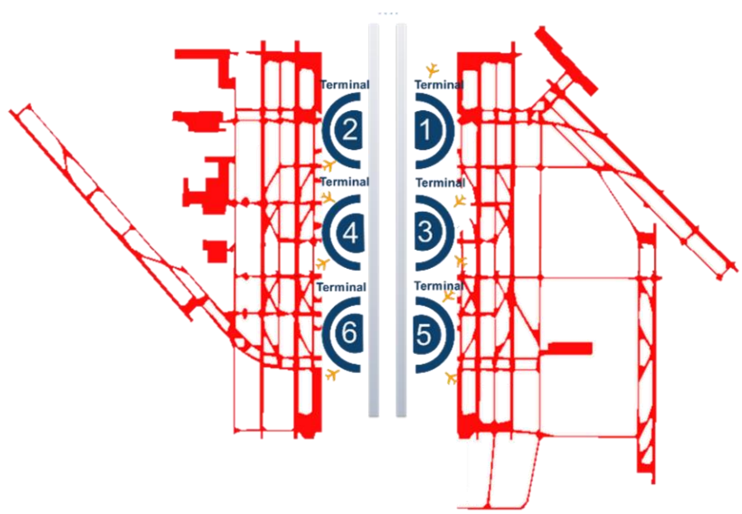


Figure 22: ***Lone Star Airport – Mock Example:*** *Campus plan highlighting terminal buildings aligned within the local Campus Coordinate System, illustrating overall building orientation and spatial relationships across the site.*

Enlarged Plan of the 6 terminals of the mock example Lone Start Airport case study.

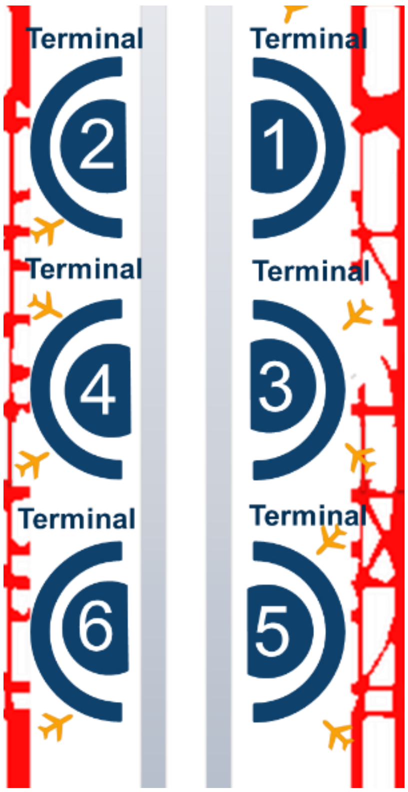


Figure 23: ***Lone Star Airport – Mock Example:*** *Enlarged view of terminal buildings showing individual terminal layouts positioned relative to the Campus Coordinate System centerline.*

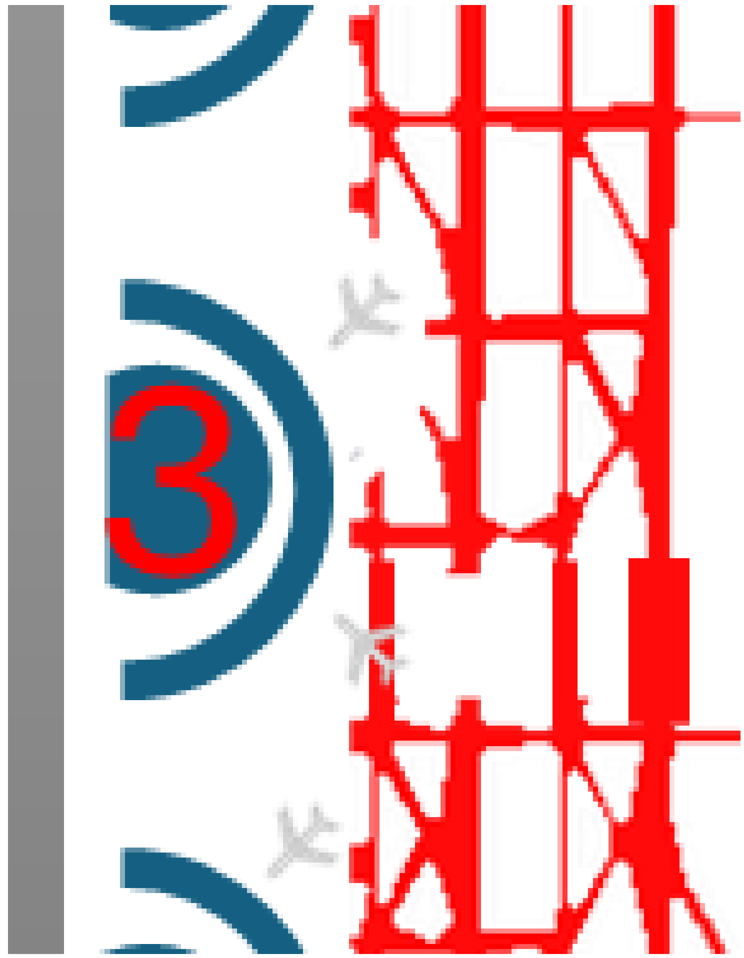


Figure 24: ***Lone Star Airport – Mock Example:*** *Detailed view of a terminal area illustrating local project geometry and element placement within the Campus Coordinate System framework. This example will look at Terminal #3 which is hypothetically built in the 1970s.*

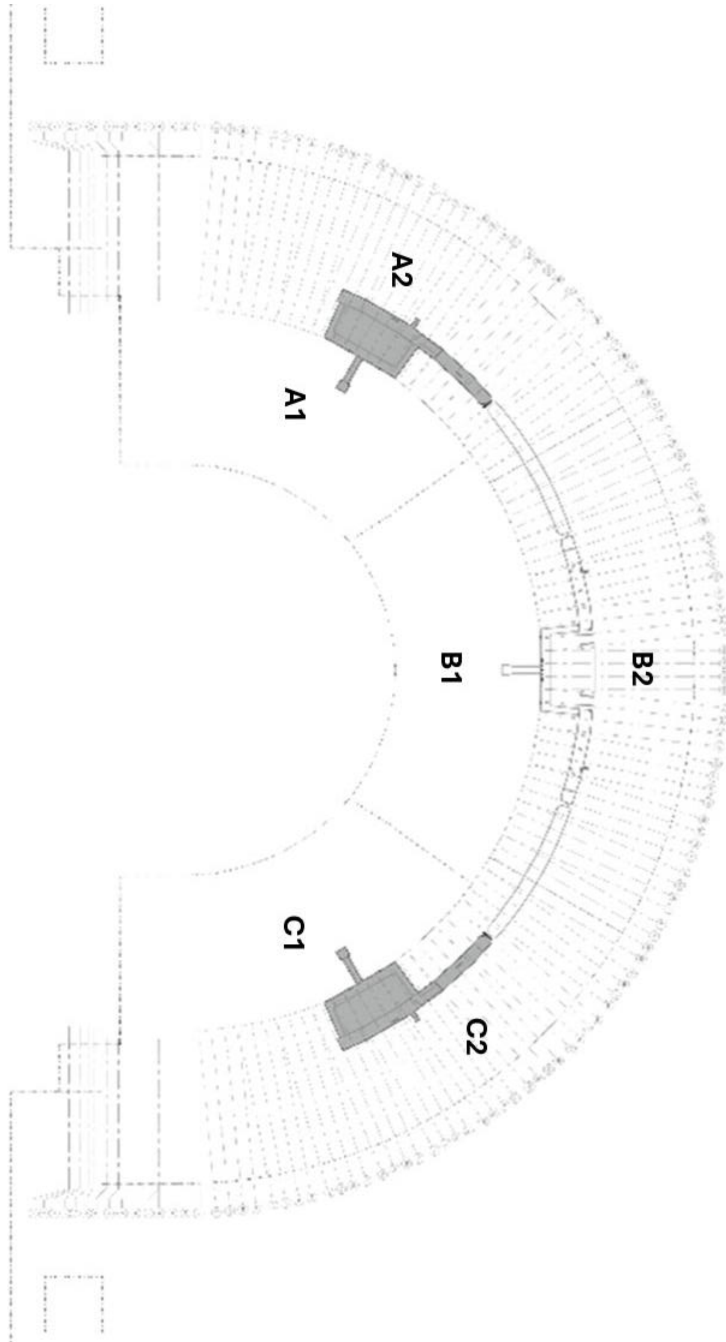


Figure 25: ***Lone Star Airport – Mock Example:*** *Radial terminal layout illustrating building segments (A, B, and C) positioned along curved geometry, emphasizing the use of a consistent coordinate system to control location and orientation within a curved campus configuration for terminal #3hypothetically built in 1970 with control set on US Survey FT.*