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Open Geospatial Consortium

# TOWARDS MATERIAL METADATA STANDARDIZATION

## DISCUSSION PAPER

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# I KEYWORDS

The following are keywords to be used by search engines and document catalogues.

ogcdoc, OGC document, physical material, ifc, bis, citygml, granta mi, 3d tiles

## II SECURITY CONSIDERATIONS

No security considerations have been made for this document.

# III SUBMITTING ORGANIZATIONS

The following organizations submitted this Document to the Open Geospatial Consortium (OGC):

- Bentley Systems, Inc
- Ansys

# IV INTRODUCTION

The industries dedicated to the Architecture, Engineering, Construction, and Operation of Infrastructure Assets (AECO) have been adopting state of the art advancements in information technologies, including Building Information Modeling (BIM), Internet of Things (IoT), and Artificial Intelligence (AI). These efforts have been leading these industries to embrace Digital Twin (DT) applications and processes in order to enhance Business Intelligence, Decision Support, and Situational Awareness. The concretion of these developments heavily rely on the overall quality, alignment, and discoverability of data in a DT. Semantical standardization of data is an important part of those requirements, which enables outcomes such as automated validation, interoperability, and simulations. This discussion paper focuses on a piece of information that is common to most of those goals: semantical machine-understanding of materials captured in a DT for AECO.

This paper presents a brief overview of the state of the modeling of materials in a sample of existing standards — IFC and 3D Tiles — and software vendor applications — Base Infrastructure Schemas (BIS), an Open Source effort by Bentley Systems, and Granta MI, a commercial Materials Data Management (MDM) system by Ansys — relevant for AECO industries. This is done in light of the needs for machine-understanding of materials in a DT for AECO.

1

# NORMATIVE REFERENCES

# 1 NORMATIVE REFERENCES

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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# 2

# ABBREVIATED TERMS

# 2 ABBREVIATED TERMS

| | |
|---|---|
| AECO | Architecture, Engineering, Construction and Operations |
| AI | Artificial Intelligence |
| BIM | Building Information Modeling |
| BIS | Base Infrastructure Schemas |
| BoMs | Bill of Materials |
| DT | Digital Twin |
| FSI | Fluid Structure Interaction |
| glTF | GL Transmission Format |
| IFC | Industry Foundation Classes |
| IoT | Internet Of Things |
| MDM | Materials Data Management |
| ML | Machine-Learning |
| PBR | Physically-Based Rendering |
| SBR | Shooting and Bouncing Ray |

3

# OVERVIEW

# 3 OVERVIEW

Proper description of Materials used in Infrastructure projects is of great importance towards ensuring the reliability and soundness of the resulting assets. This is true across all lifecycle phases of an Infrastructure Asset, from Design and Construction all the way to Operation and Maintenance.

In this context, the focus on Materials goes well beyond the visualization aspect, which is typically referred to in terms of a *Texture* or *Render Material*. It includes their semantical classifications as well as any applicable attribution needed for various use-cases during the lifecycle phases of an Infrastructure Asset.

For example, material information is key during the Design phase of an asset, dictating an important input into the overall cost-estimation of a project. It also leads to the definition of a `Bill of Materials` (BoMs), a list of raw materials, components and instructions that will be used during the Construction phase afterwards. Figure 1 shows a small sample of a BoMs, including cost-estimation, of the Slabs and Beams in an Infrastructure project that involves a Bridge's Deck. Note that Construction Materials such as Concrete or Reinforcement Steel are specified according to the corresponding classifications at Standards Organizations such as ASTM International.

| **Name** | **Quantity** | **Unit** | **Unit Cost ($/unit)** |
|---|---|---|---|
| Deck Slab | | | |
| Concrete grade C35/45 | 400 | $m^3$ | 100.00 |
| Reinforcement Steel grade A500 | 60,000 | Kg | 1.00 |
| Pre-stressed Steel grade A1680/1860 | 4000 | Kg | 3.50 |
| Deck Beam | | | |
| Concrete grade C35/45 | 120 | $m^3$ | 100.00 |
| Concrete grade C50/60 | 250 | $m^3$ | 140.00 |
| Reinforcement Steel grade A500 | 60,000 | Kg | 1.00 |
| Pre-stressed Steel grade A835/1030 | 1300 | Kg | 5.00 |

**Figure 1** — Sample of a Bill of Materials with Cost estimation

Specialized material information is required for any kind of Physics-based Simulations, which are commonly used by Architects and Engineers at various lifecycle phases of an asset. They enable predictions on their behavior under certain conditions. Structural, Thermal, Signal Propagation and Hydraulic Analyses are examples of Physics-based Simulations.

- Structural integrity is a complex multicomponent, multiphysics challenge. With new materials empowering ever bolder designs, simulation is the only way to understand performance under normal and extreme loading conditions. Two examples include Fluid

Structure Interaction (FSI) simulations[1] that can model wind load on a large structure, or seismic analysis under dynamic loading[2].

| | | | |
|---|---|---|---|
| **Isotropic Mechanical** | | | |
| | Young's modulus | 2.15 | GPa |
| | Poisson's ratio | 0.404 | |
| | Yield strength | 44.3 | MPa |
| | Tensile strength | 44.7 | MPa |
| | Elongation | 123 | % strain |
| | Elongation at yield | 123 | % strain |
| **Isotropic Thermal** | | | |
| | Thermal expansion coefficient | 100 | µstrain/°C |
| | Thermal conductivity | 0.248 | W/m.°C |
| | Specific heat capacity | 1610 | J/kg.°C |
| | Thermal diffusivity | 1.34e-7 | m^2/s |
| | Maximum service temperature | 69.1 | °C |

**Figure 2** — The definition of simple structural and thermal properties within Granta MI

Other, more advanced simulations, such as the effect of seismic loading may require more complex material models. For example, models which capture the hyperelastic behavior of rubber based damping systems, or the complex failure models of reinforced concrete.

[1] Examples of software products capable of executing FSI simulations include Ansys Fluent, Ansys Mechanical and Bentley ADINA

[2] Ansys Dyna, Bentley's STAAD and ADINA are examples of software products capable of executing seismic analysis under dynamic loading

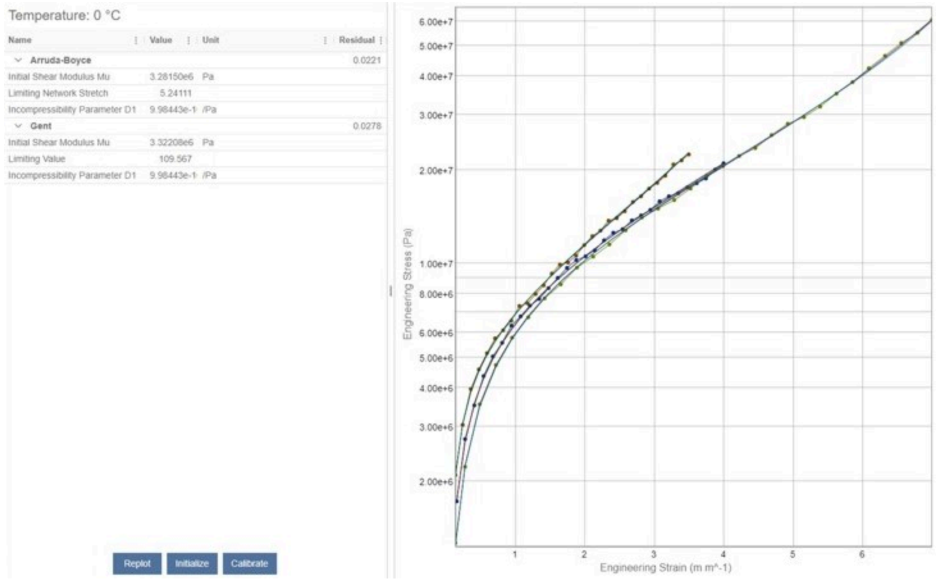


**Figure 3** — The definition of hyperelastic material models in Granta MI

- Digital models of interior ventilation are used to maximize energy efficiency and occupant comfort and safety. The combination of fluid dynamics and thermal analysis can achieve this[3].
- Radar and wireless communications designers face signal propagation challenges and automotive radar developers need accurate urban environment models to test system performance and safety, or to generate synthetic data for AI/ML training.[4].
- Water distribution and Stormwater networks, as well as drainage systems in any Infrastructure Asset, are examples of Hydraulic Systems. Their design requires executing simulations based on fluid mechanics in order to analyze the behavior of the Hydraulic System under various conditions. Specialized attribution of the materials of the components in contact with the modeled fluid are an important input to Hydraulic Analysis. Figure 4 depicts attribution needed for each material in order to execute an Hydraulic Analysis[5].

---

[3]Ansys Fluent is a software product capable of combining fluid dynamics with thermal analysis

[4]Software products such as Ansys Perceive EM can accurately model signal propagation in real-time through Shooting and Bouncing Ray (SBR) technology

[5]Bentley's OpenFlows offerings are examples of software products capable of executing hydraulic analysis

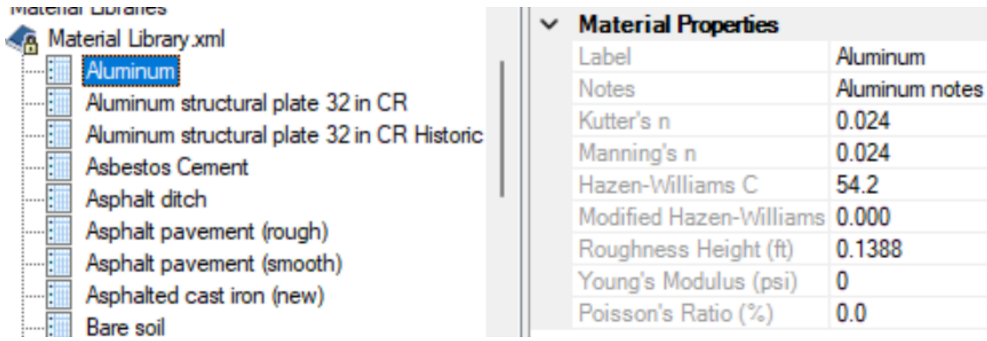


**Figure 4** — Material properties needed for Hydraulic Analysis

In general, all of these physics-based simulations require accurate material properties and models to deliver accurate results.

Material information is also part of other important tasks in Infrastructure Projects. An average project spanning the design, construction, operation or maintenance of an Infrastructure Asset typically involves several multi-disciplinary teams that need to work sometimes in parallel, other times sequentially, while still keeping a high level of coordination of their efforts. Thus, Data Interoperability is crucial to enable the correct exchange of information among teams, while Data Validation is a necessity in order to ensure no errors are introduced during such processes.

Advancements in AI and IoT have been raising the need for Infrastructure data to be captured in ways that machines can understand it without Human intervention, which enables the automation of processes and tasks such as the ones previously described. This bold requirement translates into systems having to generally capture semantics and details of the concepts modeled in a standard and consistent manner. That need naturally applies to the semantics and attribution of materials in an Infrastructure project.

The following clauses in this paper present an overview of the state of the art of the modeling of materials in the international standards and software vendor technologies listed below:

- IFC by buildingSMART
- 3D Tiles by OGC
- Base Infrastructure Schemas (BIS) by Bentley Systems
- Granta MI by Ansys

# 4

# MATERIALS IN IFC

# 4 MATERIALS IN IFC

Industry Foundation Classes IFC are a set of standardized, digital descriptions of the built asset industry. It is an open, global standard published under a Creative Commons license, and as ISO 16739. IFC provides machine interoperability of information and thereby enables automation of workflows. IFC is developed by buildingSMART.

Its class hierarchy includes IfcMaterial, whose instances represent "*a homogeneous or inhomogeneous substance that can be used to form elements (physical products or their components)*".

## 4.1. Material Classification

Instances of `IfcMaterial` can be identified via the class' `Name` string-based attribute, which may be required to be unique in a project. This attribute is appropriate to capture material names at the level needed by Reporting use-cases, such as Bill of Materials.

The `IfcMaterial` class also includes a `Category` string-based attribute in order to capture a very general classification of materials. Examples include *concrete*, *steel*, *aluminum*, etc. Values in the `Category` attribute are not standardized by IFC. Figure 5 shows an instance diagram with sample instances of the `IfcMaterial` class that capture various steel grades.

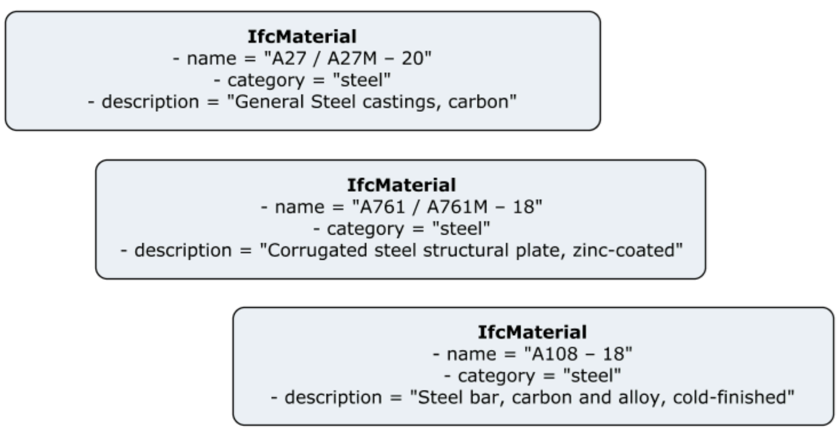


**Figure 5** — Sample IfcMaterial instances

IFC can optionally capture Material Classifications defined by International Standards as instances of IfcClassificationReference, which can then be associated to `IfcMaterial` instances via IfcExternalReferenceRelationships. In that case, instances of `IfcClassificationReference` are expected to carry sufficient information to interpret material classification according to the names or *classification keys* defined by a specific Classification System.

Figure 6 shows a class diagram summarizing the three approaches available in IFC for material classification:

- IfcMaterial.Name
- IfcMaterial.Category
- IfcClassificationReference

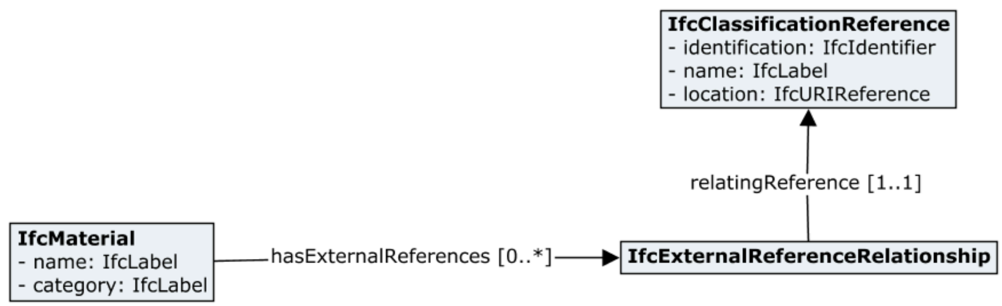


**Figure 6** — Material Classification concepts in IFC

Figure 7 shows an instance diagram with a sample of `IfcMaterial`s and their associations to `IfcClassificationReference`s.

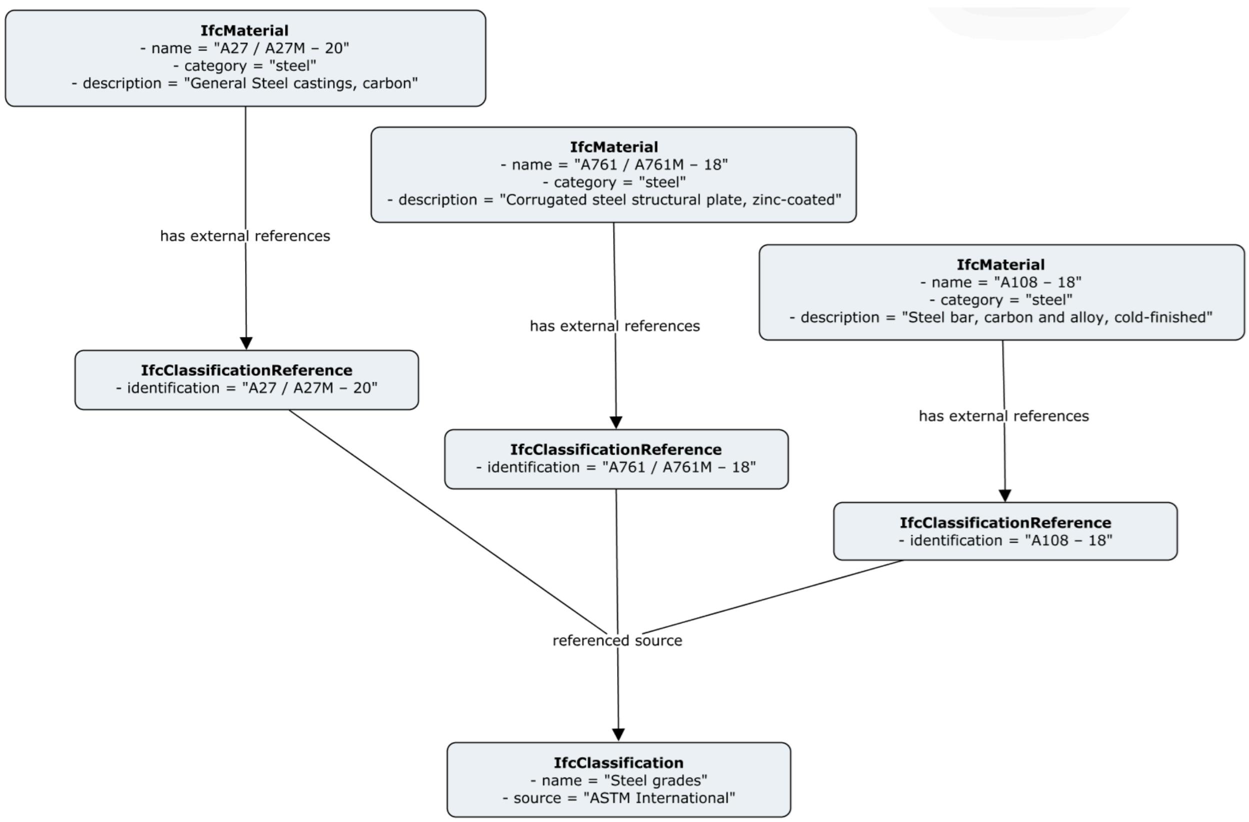


**Figure 7** — Sample of Material Classification with IfcClassificationReferences

## 4.2. Material Attribution

Specialized attribution associated to an instance of `IfcMaterial` are handled via sets of material properties captured by an instance of the IfcMaterialProperties class. IFC standardized several *Property Sets* applicable to `IfcMaterial`s that are normally used in various kinds of Simulations. The following table lists a sample such *Property Sets* and their associated kinds of Simulations.

**Table 1** — Sample of *Property Sets* that capture specialized material attributes with applicable Kinds of Simulations

| Property Sets | Example of Applicable Simulation |
|---|---|
| Pset_MaterialMechanical | Structural Analysis |
| Pset_MaterialConcrete | Structural Analysis |
| Pset_MaterialWood | Structural Analysis |
| Pset_MaterialSteel | Structural Analysis |
| Pset_MaterialEnergy | Energy Analysis |
| Pset_MaterialThermal | Thermal Analysis |
| Pset_MaterialWater | Water-Quality Analysis |

# 5

# MATERIALS IN 3D TILES

# 5 MATERIALS IN 3D TILES

## 5.1. Overview

`3D Tiles` is an open standard, published by OGC, designed for streaming and rendering massive 3D geospatial content such as Photogrammetry, 3D Buildings, BIM/CAD, Instanced Features, and Point Clouds. It defines a hierarchical data structure and a set of tile formats which are used to efficiently manage and display 3D content, optimizing performance by dynamically loading appropriate levels of detail.

`3D Tiles` allows for the encoding of information associated to any level of its hierarchical data structure — including tile-set, tile, individual geometry and a pixel within it. `3D Tiles` refers to information associated to any of the levels of such hierarchy as *metadata*. Figure 8 shows an example of *metadata* assigned at various granularities in a hierarchical tile structure.

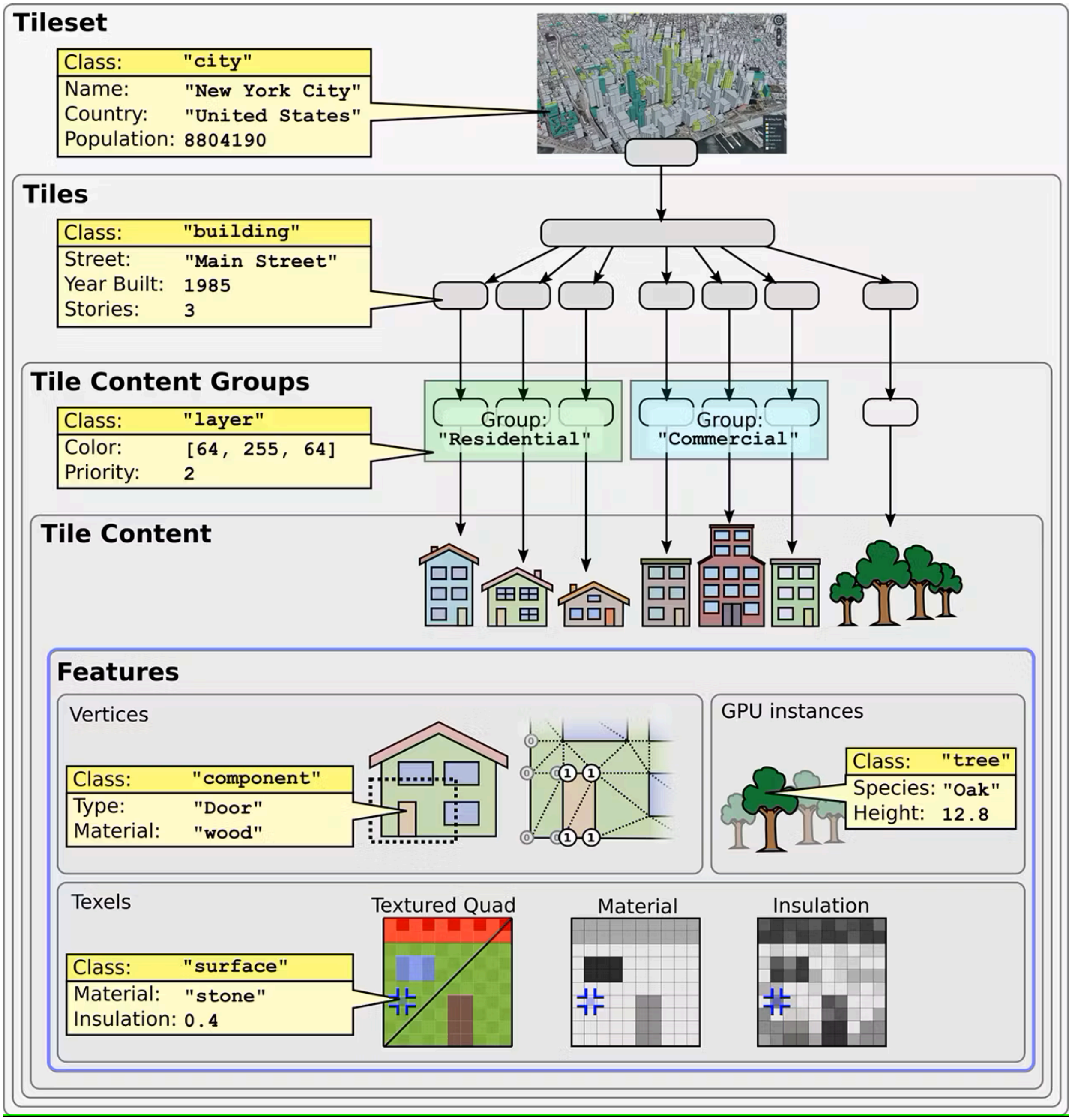


**Figure 8** — Example metadata at various granularities in 3D Tiles

## 5.2. Materials in 3D Tiles

Referring specifically to materials, `3D Tiles` can deliver photorealistic visuals by using Physically-Based Rendering (PBR)[6]. Moreover, `3D Tiles` can capture semantics behind any

[6]PBR is implemented by GL Transmission Format (glTF) used in `3D Tiles`

attribute, as part of its *metadata*. The `3D Tiles` specification includes the standardization of some common semantics used by *metadata* properties. However, at the time of this writing, such standardization of semantics has not included any classification or attribution of material information yet.

Nevertheless, a specific implementation of `3D Tiles` can still capture material-related information by introducing it as application-specific attributes. The following class declaration snippet, encoded in JSON according to the `3D Tiles` specification, shows the definition of a two string properties named `Material_Name` and `Material_Grade`, onto a class named `Column`.

```
{
  "entity": {
    "class": "Column",
    "properties": {
      "stringProperty": "Material_Name",
      "stringProperty": "Material_Grade"
    }
  }
}
```

**Listing 1 — Sample material properties added to a class for 3D Tiles, encoded in JSON**

6

# MATERIALS IN BIS

# 6 MATERIALS IN BIS

BIS stands for Base Infrastructure Schemas. It is an ecosystem of modular schemas for modeling concepts and data about an Infrastructure Asset. It is an Open Source effort led by Bentley Systems, Inc.

BIS models Materials with two parallel concepts, as follows:

- Render Material: captures the rendering properties of materials for display purposes; and
- Physical Material: focuses on describing the matter of which physical objects are made of.

Thus, BIS' Physical Material is the concept relevant for the main topic of this discussion paper.

## 6.1. Material Classification

A Physical Material in BIS is modeled via a class-hierarchy with a common base-class — `PhysicalMaterial` — defined under the `DefinitionElement` branch of the ecosystem. `DefinitionElement`s in BIS model information meant to be referenced or shared. Figure 9 depicts some of the Physical Material classes that BIS has standardized so far in its ecosystem.

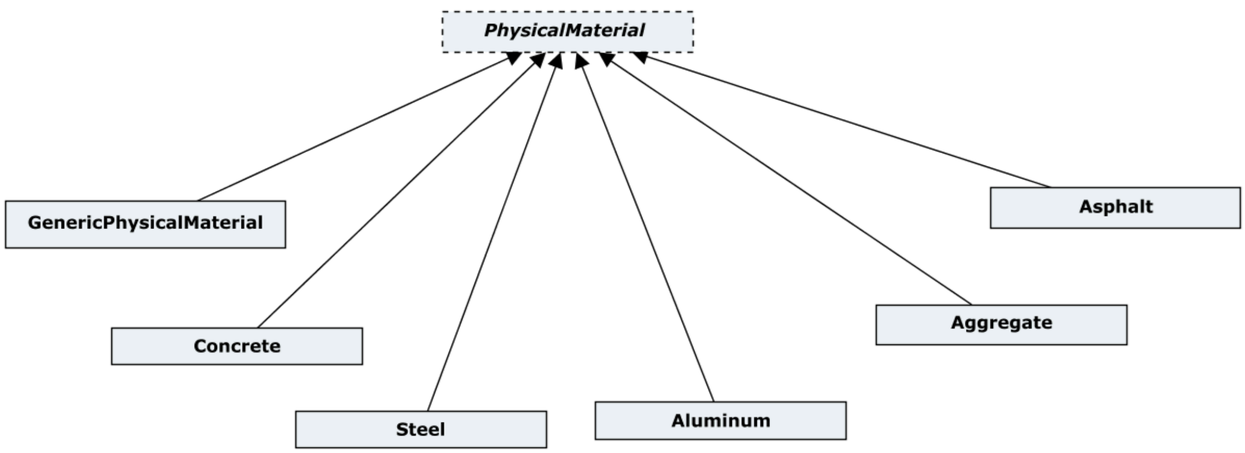


**Figure 9** — Material Class Hierarchy in BIS

BIS uses the `PhysicalMaterial` class-hierarchy to encode a general classification of materials that can be understood by machines. More specific classifications can be captured in BIS via one of the following two approaches:

1. By capturing *well known names* or *classification keys* as `Codes` of the instances of any concrete `PhysicalMaterial` sub-class; or

2. By capturing *well known names* or *classification keys* in instances of the `Classification` class that are associated with corresponding `PhysicalMaterial` instances.

Any instance in the BIS ecosystem, called *Element*, can optionally carry a human-friendly *business key* that is unique in a certain context, and thus, it can be used as a form of identification. This special property of any BIS *Element* is referred to as *Code*. The first approach listed above relies on the *Code* property of `PhysicalMaterial` instances to capture the desired *classification key*. Figure 10 shows a few sample instances of the `Steel` class, with their *Code* properties assigned to their *classification key* according to ASTM International.

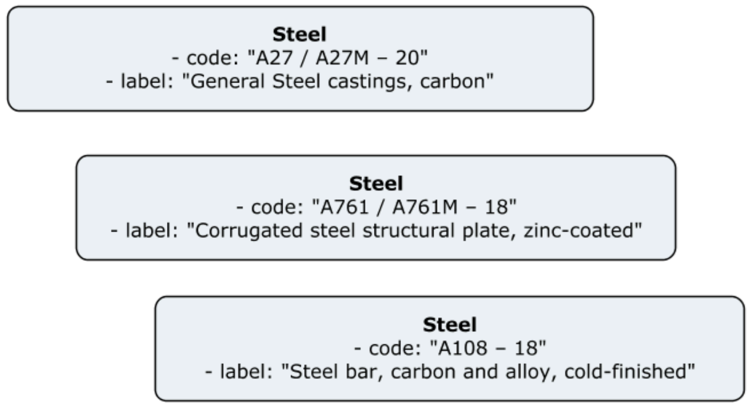


**Figure 10** — Sample Steel Instances with classification keys and descriptions

The BIS ecosystem contains a set of classes meant to capture *Classification Systems* that can be used to provide additional classifications in parallel to BIS instances. They can be used to capture a more complete representation of a *Classification System*, or to classify any BIS instance according to one or more *Classification Systems* in parallel. Figure 11 shows the same `Steel` instances from Figure 10 but this time associated to more complete classification tables according to ASTM International, by using BIS *ClassificationSystems_* classes.

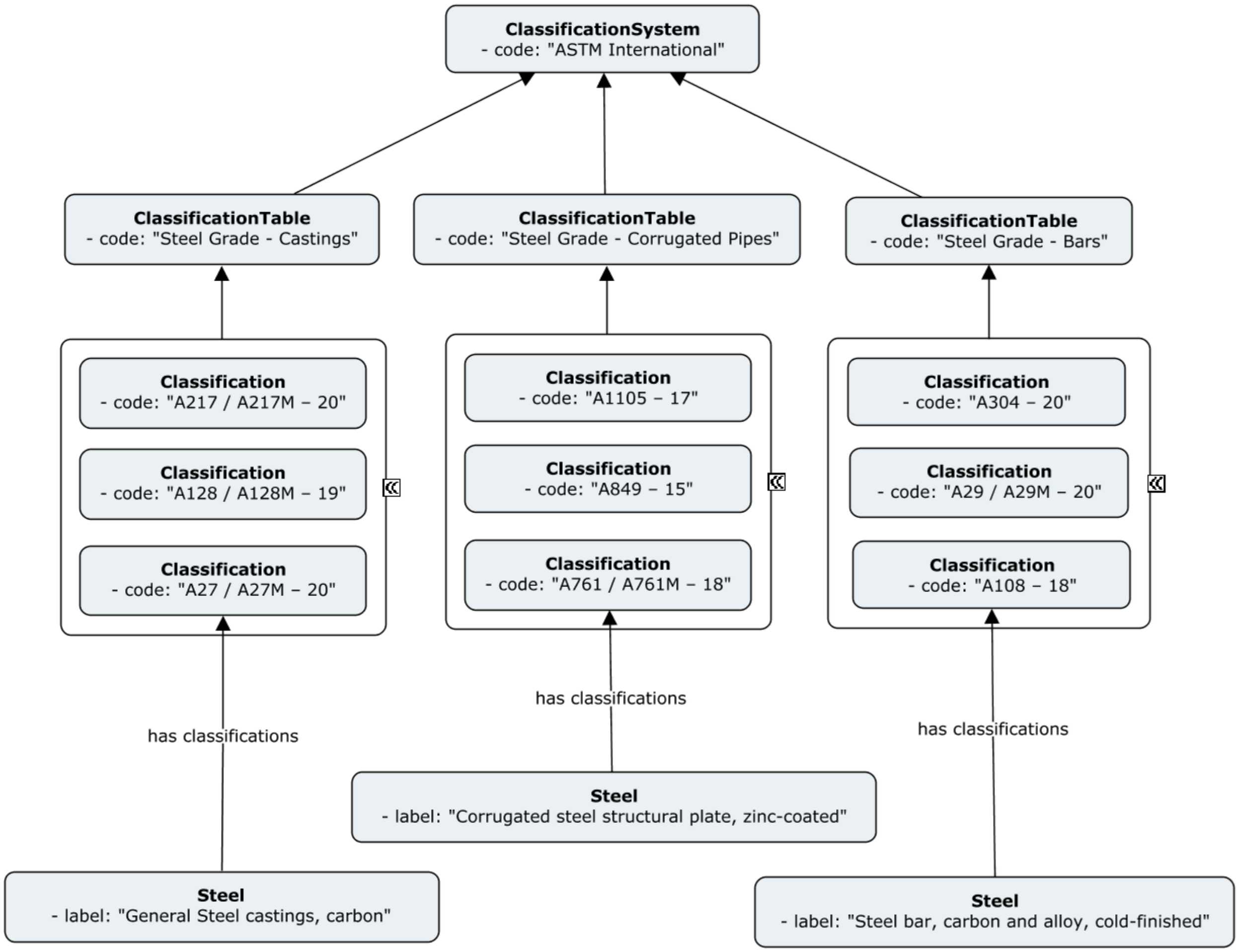


**Figure 11** — Sample Steel Instances classified based on BIS ClassificationSystems classes

## 6.2. Material Attribution

Being modeled as instances, `PhysicalMaterial` *BIS elements* can carry specialized attribution. In general, BIS offers two approaches to capture attribution information for any *element*:

1. As first-class properties of a BIS Element-class
2. As properties of a BIS Element-Aspect class

The second approach is the one applicable to material attribution. A BIS Element-Aspect class captures sets of properties that can be optionally attached to an *Element* instance. In the case of Material attribution, it enables the definition of Element-Aspect classes that capture sets of properties per specialized Kind of Simulation. These *Element-Aspects* can then be associated to particular `PhysicalMaterial` instances. Figure 12 shows instances of the `Steel` class, attributed with mechanical properties, defined in the `SteelMechPropertiesAspect` *Element-Aspect* class, attached to those instances.

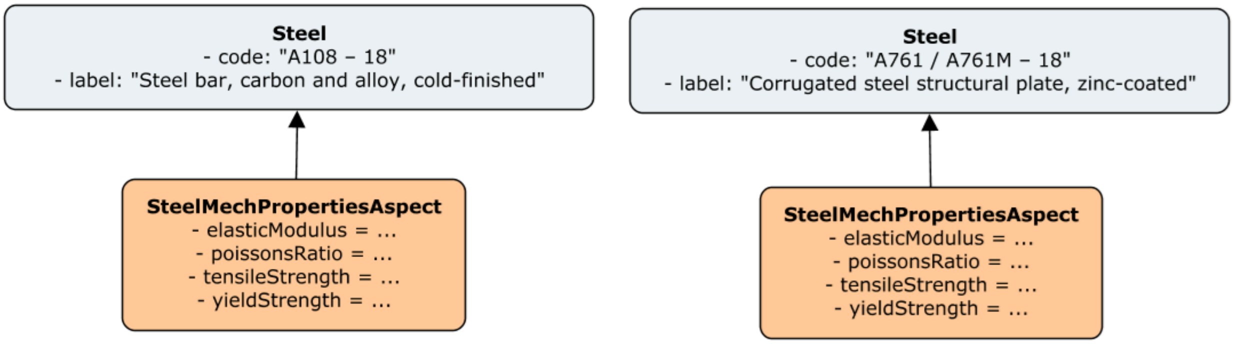


**Figure 12** — Sample Steel Instances with Attribution via Element-Aspects

The following table lists a sample of *Element-Aspect* classes in the BIS ecosystem that capture specialized material attribution and their associated kinds of Simulations.

**Table 2** — Sample of *Element-Aspect* classes that capture specialized material attributes with applicable Kinds of Simulations

| Element-Aspect | Example of Applicable Simulation |
|---|---|
| GenericMechPropertiesAspect | Structural Analysis |
| ConcreteMechPropertiesAspect | Structural Analysis |
| SteelMechPropertiesAspect | Structural Analysis |
| HydraulicMaterialAspect | Hydraulic Analysis |

7

# MATERIALS IN GRANTA MI

# 7 MATERIALS IN GRANTA MI

## 7.1. Overview

Granta MI is a commercial Materials Data Management (MDM) system by Ansys and has been developed over the last 20 years to manage materials data for many industries and applications including design & simulation, test data management, sustainability, and computational materials design. It has a flexible schema, which allows it to be configured to many different use cases, but to aid implementation and standardization a number of templated configurations have been developed incorporating best practice for MDM. The use of schema element *building blocks* allow new configurations to be quickly developed, while retaining the best practice standards and interoperability with downstream systems such as simulation.

## 7.2. Material Classification

As Granta MI is a database system, each material is represented as a record in the system. There are two methods to classify materials.

- Tree based hierarchy: A parent-child hierarchy of record groups can be defined allowing for a very flexible classification system that can be intuitive for users to navigate. This gives the flexibility to classify materials from many different material classes, e.g., metals, polymers, composites, and glasses where the method of classification can vary widely. However, this tree structure is more difficult to navigate and interrogate programmatically which is a requirement for seamless integration into digital engineering and digital twin workflows.

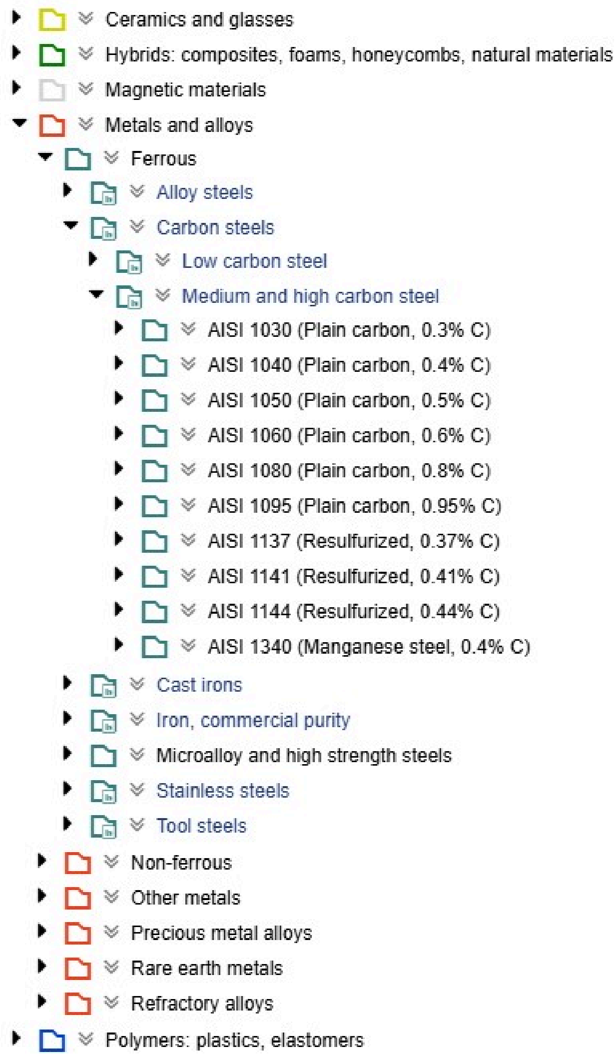


**Figure 13** — A typical hierarchical materials classification in Granta MI

- Attribute based: Rather than a hierarchy, each material can be classified by a number of different attributes which by combination, will uniquely identify that material. These are the most common classes of attributes used to describe a material.
  - Composition: How the composition of a material is classified varies between material class. Metals are defined by elemental composition, polymers by polymer class and any reinforcements, fillers or additives, and concretes by cement, aggregates, additives and reinforcements.
  - Form, Processing & Post-processing: The form of the material, such as sheet, tube, or fiber, is important for inclusion in BoMs, but can also have an impact on its properties. How the material is processed, or any post-processing steps, such as heat-treatment, can have a major impact on performance, but varies between material classes.
  - Performance: Some materials are classified by their properties or performance, for example the strength or hardness of a metal, the optical qualities of glass, or the thermal performance of insulation.

- Standards: Many industries define standards for the materials used, and can be a combination of composition, form and performance, and will often define minimum requirements.

The use of these attributes means that the materials can easily be filtered and analyzed by the user and programmatically. A tree hierarchy can also be built from these attributes giving flexibility in user experience. However, when classifying many different material classes, the number of attributes required will be large, leading to redundancy. Granta MI has a number of standard templates to classify materials, from a simple set of attributes which can be used across all material classes, to more complex sets for a detailed classification of a particular class of materials.

| Composition overview | |
|---|---|
| Compositional summary | Blend of: Acrylonitrile Butadiene Styrene (ABS) + Polyamide (PA6 or PA66), with glass fiber reinforcement and UV stabilizer |
| Form | Bulk material |
| Material family | Plastic (thermoplastic, semi-crystalline) |
| Base material | ABS+PA (Acrylonitrile butadiene styrene + polyamide/nylon blend) |
| % filler (by weight) | 8 % |
| Filler/reinforcement | Glass |
| Filler/reinforcement form | Short fiber (<5mm) |
| Additive | UV stabilizer |
| Polymer code | (ABS+PA)-GF10 |

**Figure 14** — A simple attribute-based classification system in Granta MI

## 7.3. Material Attribution

The properties of materials are captured in Attributes defined in the schema. Like most database systems, these attributes can be a number of different data-types, e.g. numerical, text, lists, files and images. As the system was developed specifically for engineering data, it has a number of complex data types that can be utilized such as tables, grids, data series, and mathematical expressions. This allows for a very flexible data structure, but for key use cases, preconfigured templates are available to promote best practice, standardization and interoperability.

8

# CONCLUSION

# 8 CONCLUSION

This discussion paper aimed at highlighting the increasing need for richer material data that machines can understand, both in terms of semantical classification as well as attribution. This paper focused on the AECO industries, as these needs have risen as they have adopted state of the art advancements in information technologies, especially Digital Twin (DT) applications and processes.

This paper also presented summaries of the current state of a few schema ecosystems with respect to materials. From the two international standards discussed, IFC ranked better at addressing most of these needs. It treats materials as a first-class concept that can be attributed. Some common specialized material-properties are standardized in its ecosystem. Furthermore, even though it has not standardized a classification of materials on its own, IFC allows implementors to capture them in parallel.

Still, the schema ecosystems led by software vendors that were discussed go beyond that. They aim at standardizing material semantics, classification, and attribution on their ecosystems — a key goal that enables generic automation downstream. The BIS model focuses on the standardization of semantical classification and attribution of materials relevant in the AECO industries. Granta MI further inspires by showcasing additional functionality that can be built on top of a rich semantical model, including template-driven and attribution-based classifications.

On the other hand, the `3D Tiles` international standard was discussed as an example of a schema ecosystem that currently lacks standardization of material semantics and attribution. Other international standards, such as CityGML, would greatly benefit from a similar evolution as well.

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# BIBLIOGRAPHY


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