Civil Systems Engineering

Modeling Engineering Products

Assignment #1

Scaffolding Ontological Modeling

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Declaration of Authorship

I declare that all material in this submission is my own work except where there is clear acknowledgement and appropriate reference to the work of others.

Signature: Date: 7/12/2020

1. Civil engineering system selection

Scaffolding systems are temporary structures which enable various types of access and working area for, among other purposes, building or civil infrastructural projects. Due to their temporary nature, their importance and elegance can be overlooked and underappreciated. Despite this, designing an efficient scaffolding system can pose a fascinating engineering challenge, and their success and reliability are fundamental for projects at every scale. Just some of the key considerations when designing scaffolding systems are that they should be;

- designed for rapid assembly and disassembly
- durable (work, transport, weather)
- adaptable to a wide variety of interfaces
- extendible (ie. modular)
- cheap
- able to strike a balance between safety and simplicity
- light to transport and assemble

From the point of view of developing a first ontology, a scaffolding system strikes a healthy balance between simplicity (with a limited number of components) and complexity (as it may interface with infinitely different situations). The inherent modularity (with the ability to build systems upon systems) makes for an interesting exploration of various axioms while the limited options of the simple system provide an easy to understand example of conditional statements in developing restrictions within the ontology.

This being said, the variety of types and different arrangements within the scaffolding domain are many, making it important to define our scope for this study.

2. Background research and ontology scope

The Designing Buildings Wiki [1] defines the function of scaffolding as providing a temporary safe working platform for activities such as:

- Maintenance
- Construction
- Repair
- Access (extremely broad definition)
- Inspection

Particularly the term *'access'* means that the scope for how scaffolding systems can be utilised is vast. Anything from providing a working platform for builders and their materials on a construction project to raising a stage for musicians or actors in a performance to keeping the feet of visitors to Venezia dry during the *acqua alta,* the time of year when the streets of the city are flooded. The possibilities are, quite literally, endless.

Historically speaking, there is written evidence for the use of scaffolding in constructing the Pyramids in ancient Egypt. The Greek historian Herodotus writing in the 4th Century BC [2] explains that;

> *"the pyramid was built with steps, like a staircase….The stones intended for use in constructing the pyramids were lifted by means of a short wooden scaffold. In this way they were raised from the earth to the first step of the staircase; there they were laid on another scaffold, by means of which they were raised to the second step…. The finishing-off was begun at the top, and continued downward to the lowest level."*

Still further back (approx 3000BC), and with the only evidence of past structures in the forms of remaining standing stones, archaeologists can infer that some forms of scaffolding must have been used by Neolithic societies at that time in the erection of great Portal Tombs [3], the example below from close to the historic family home of the author.

Fig. 1 - The Neolithic peoples who built Proleek Dolmen portal tomb (Co. Louth, Ireland circa 3000BC) likely utilised some early form of scaffolding [3].

Perhaps some of the most impressive examples of construction in the early modern period come in the form of the great Gothic Cathedrals of Europe, the medieval monks being skilled in the erection of vast and intricate scaffolding systems of wood. This tradition of masonry monks remained in use well into the 20th Century [2]. To this day, the remains of scaffolding holes can be a common method for archaeologists to date and understand the construction sequence for historic buildings long after their builders have gone.

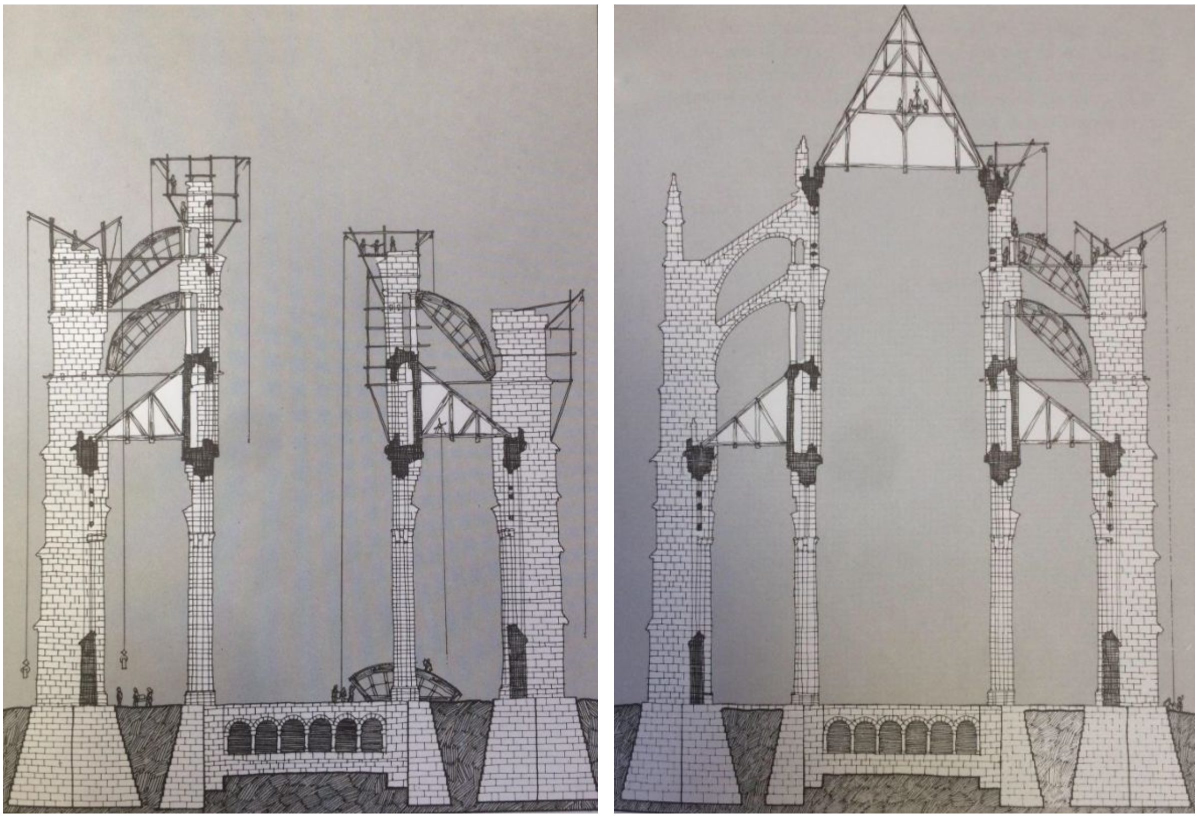


Fig. 2 - Shoring type scaffolding being used to support *Flying Buttresses* of a gothic cathedral during construction in the middle ages [4].

In terms of materiality, scaffolding would have been traditionally made of wood or bamboo (which remains the dominant material choice in much of Asia) depending on availability and it was not until the 20th Century that the use of steel became common, the standardised tube sizes and inherent strength and durability lending themselves well to the development of systems of interchangeable parts [5].

Fig. 3 - Hong Kong, the city famous for towering bamboo scaffolding (images courtesy of Pond5.com).

In the modern period scaffolding is usually composed of galvanised steel or aluminium (with bamboo remaining prevalent in places, as discussed above) and can be broadly grouped into the following types [5][6];

1. **Single Frame**, historical system where ledgers are tied into the work area
2. **Double Frame**, most common type today and the system of focus for this ontology
3. **Suspended**, where a platform is lowered from adjustable cables
4. **Cantilevered**, where the system is free from ground contact, anchored to the object
5. **Mast Climbing**, where a platform climbs vertical masts
6. **Shoring**, enabling the pouring of concrete but also in the erection of masonry arches
7. **Trestle**, for working on the underside of surfaces (think Sistine Chapel), may have lockable wheels today.

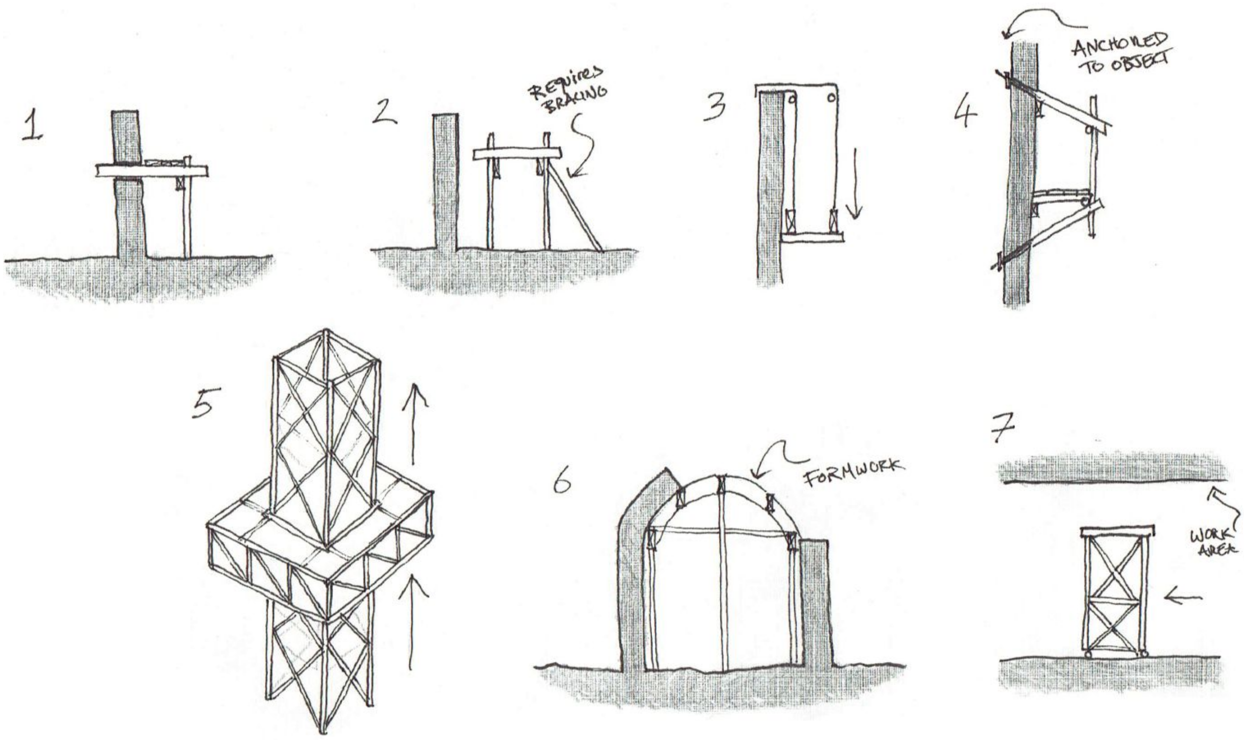


Fig. 4 - Scaffolding types and how they interface with the work area.

Today, brands such as *Haki* and *Kwikstage* have become almost synonymous with the domain. These major industry players utilise a tube & clamp system of light weight, easily assembled frames and platforms of interchangeable parts. Innovation in the domain continues however, with an ever greater focus on safety for those assembling and using the systems.[1]

[1] The author has been acquainted with some recent examples at one major construction site in Berlin with a far greater focus on safety (in the form of complex locking mechanisms) and there appears to be a move even towards digitising some of these processes.

For the purposes of this ontology we will limit the scope to a specific arrangement[2] of the *Double Frame* type scaffolding, a variation on the tube & clamp system, whose components and domain terminology, are listed and described below (See Fig. 5). The system comprises:

- 4 x **Standards*** (columns) of varying length (2600mm and 3200mm) with tube diameter: 48.3mm and thickness: 3.2mm. Standards have 4 directional slots for connecting to horizontal members at various heights.
- 4 x **Lattice Girders*** of length 2900mm with a combination of plates (3.2mm) and tubes of diameter: 30mm and thickness: 2mm (includes connection piece and pin-locking mechanism).
- 4 x **Ledger Girders*** of length 1400mm with a combination of plates (3.2mm) and tubes of diameter: 30mm and thickness: 2mm (includes connection piece and pin-locking mechanism).
- An optional **Diagonal Bracing*** bar with length 3450mm, tube diameter: 48.3mm and thickness: 3.2mm. Includes rotating collar and wedge locking mechanism at each end which connects to vertical Standards.
- Optional 4 x **Screw Jacks*** upon which Standards sit. An adjustable component can be screw raised with a range between 150-350mm to adjust for variations in ground level at each corner.
- 3 x **Platform Elements** make up a level. Each is composed of rough-cut 38mm timber boards. They rest on the Lattice girders and the connecting board (running perpendicular underneath and screwed to surface boards) is slotted tight between girders. Platform elements are not fixed in place but are secure due to their weight.

*Grade for all steel components is Q345 with a hot dip galvanized surface treatment.

[2] The specific scaffolding system is one which the author became deeply familiar with while recently managing a construction project in Finland. The flexibility and simplicity of the system was fascinating. This fascination was provoked with renewed interest during the abstract, Platonian exploration of ontology development, leading to the system selection.

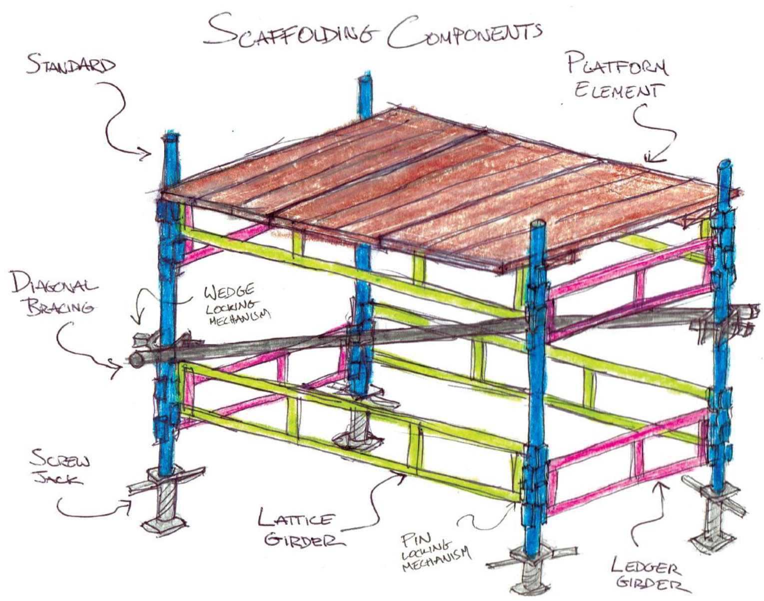


Fig. 5 - Components (bottom of 'T') of the scaffolding ontology scope

The system can be rapidly assembled and deconstructed with just 2 people (1 is possible, but 2 recommended) and the only tool required being a hammer (for slotting connections and tightening bracing member wedge locks). 2 lengths of vertical Ledger are available Standard2600 and Standard3200 enabling platform height extension. All other components are standard sizes. A second platform may be added to the lower lattice girders (ScaffoldingDoublePlatform), however, in this case diagonal bracing becomes inconvenient and should be removed (not (hasComponent some DiagonalBracingComponent)). Note that, in this case, it is necessary the scaffolding frame to have at least one side attached frames for stability hasInterface some AttachedModuleInterface . Higher platform frames using the longer column type Standard3200 must be in contact with the ground, but may have smaller adjoining frames stacked above (AboveInterface). Where a scaffolding frame is in contact with the ground it should have Screw Jacks (hasComponent exactly 4 ScrewJackComponent) to adjust independently for variation in the ground level. In the case that a frame is stacked on top of another frame (as in the case of SinglePlatformRaised), Screw Jacks are not required, the standards slotting together directly (not(hasComponent some ScrewJackComponent)).

Frames can be connected from above and below, as well as from all 4 sides. In this way, the system can be extended indefinitely. It is a system of systems, however this is not captured in the scope of this ontology. Neither safety equipment (such as railings, kick-plates) or provision for vertical movement (such as ladders) are addressed within the scope of this ontology definition.

3. Developing the ontology

In order to better define the specific ontology scope, the following competency questions and answers were defined.

1. What is the **purpose**?

The purpose of the ontology is to enable the provision of safe platforms at height by a scaffolding supplier to a client. It facilitates the design, construction and deconstruction of an individual scaffolding frame, inferring knowledge about what may be required by adjoining frames given specific design decisions based on predefined constraints, and provides information about safety, timeframe and responsible stakeholders.

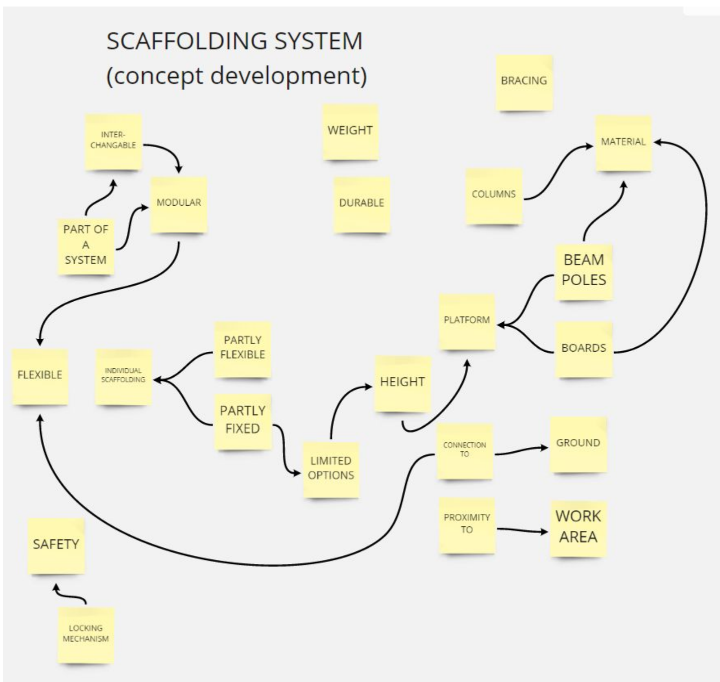
2. What is the **scope**?

   As there are many varieties of scaffolding system (described in the preceding sections) the scope is limited to a specific chosen type of steel and wood system used by the aforementioned supplier, the details of which have been previously noted.

3. Who are the intended **users** and **uses**?

   The users of the ontology are likely to be involved in the planning and design of systems for a clients' project, although information contained within the ontology may be of interest to other stakeholders. For example, perhaps the person erecting frames may wish to generate inferred knowledge about adjoining frames in order to reserve them for an upcoming project. In turn, other stakeholders are likely to contribute to the ontology. For example, safety inspection personnel may sign off on locking mechanisms being secured in place or update erection dates to reflect delays in a schedule.

Development began with brainstorming (using diagramming tools) and roughing-out the ontology hierarchy using bullet lists, though the greatest clarity resulted through focus on the competency questions (updating them in an interactive process throughout) and considering the 'T' analogy (as described by Ungureanu during labs sessions) to establish horizontal *related* concepts, and vertical *essential* concepts for the ontology.



owl:Thing
- **Scaffolding**
  - Option1 - N
- **ScaffoldingUse**
  - Maintenance
  - Repair
  - Construction
  - Inspection
- **ScaffoldingStakeholder**
  - ObjectDesigner
  - Supplier
  - Worker
  - Inspector
- **ScaffoldingMaterial**
  - WoodMaterial
  - SteelMaterial
- **ScaffoldingInterface**
  - Ground
  - Object
  - AdjoiningScaffolding (like self)
    - StackedModule
      - Above
      - Below
    - AttachedModule
      - Right
      - Left
- **ScaffoldingComponent**
  - FrameStructure
    - VerticalColumn (standard)
    - HorizontalGirderLong (lattice girder)
    - HorizontalGirderShort (ledger)
    - DiagonalBracing
    - Screw jack (flexibility to ground, max-min)
    - LockingMechanism (in many places)
      - Pin (free pivoting piece locking horiz.)
      - Wedge (diagonal bracing)
  - PlatformStructure

Fig. 6 - Early development activities for the ontology, exploring relationships and hierarchy

Sketching exercise were also helpful (as recommended by Noy & McGuinness [7]) In order to demonstrate the principles of inheritance, a simple set of 4 options were defined (as described in Fig. 7). Restrictions were defined so as to make most efficient use of the ontology in terms of sharing common attributes between classes (ie. shared attributes are codified in their highest possible class). The result is minimal duplication as demonstrated by the small number of *SubClass Of* restrictions within the lower order of classes. For example, the class SinglePlatformTall has just one restriction hasComponent value Standard3200 , having inherited all other required restrictions from ancestor classes.

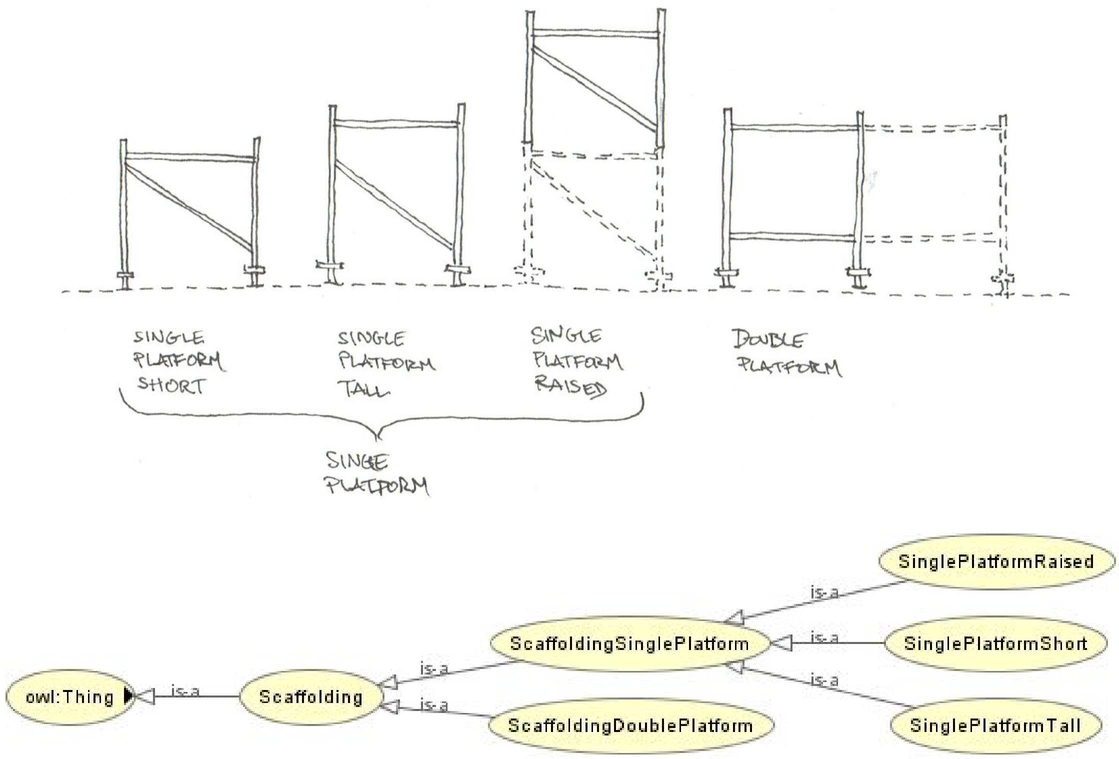


Fig. 7 - Above: Design options encoded into the ontology (with ghost AdjoiningScaffoldingInterface restrictions), below: *is-a* relationships between options visualised in Protege via OWLViz.

In terms of how Object Properties were managed, it was decided to minimise developing sub-classes and opt to reuse common concepts at multiple levels. For example, hasComponent is used to connect both FrameComponent and PlatformComponent to the associated scaffolding design options (instead of *hasFrameComponent, hasPlatformComponent* etc.).

Similarly, Data Properties were thought of as being common to multiple frame members, such that Standard3200 and PlatformComponent may share a common Data Property hasLength . This can be understood as reflecting the shared parameters concept between BIM objects (instead of hasStandardLength, hasPlatformLength etc.).

Despite the rigid and minimal options allowed in the described scope for framing, the scaffolding domain has an inherent necessity to be applied to infinitely various situations. This is demonstrated in how ScaffoldingInterface has been implemented to the ontology. As an example, the interface with ground and the need for flexibility has been encoded in the instantiation of a single ScrewJackComponent with Data Properties including hasMaxExtension and hasMinExtension , allowing for adjustment in each footing of the scaffolding frame.

Table 1 (next page) provides examples of the Logical Axioms used in the scaffolding ontology which have been implemented and documented by referring to [8],[9] and [10].

Axiom	Semantics DL	Protégé syntax for axioms implementation
Individuals		Individuals
Atomic concept	A^I	Scaffolding
Individual name	a^I	SinglePlatformTall
Roles		Object Properties
Atomic role	R^I	hasComponent
Inverse role	$\{\langle x, y \rangle \mid \langle y, x \rangle \in R^I\}$	isComponentOf
Concepts		Classes
Intersection	$C^I \cap D^I$	All ScaffoldingComponent made of SteelMaterial
Union	$C^I \cup D^I$	All ScaffoldingComponent which hasMaterial SteelMaterial common to ScaffoldingSinglePlatform and ScaffoldingDoublePlatform
Complement	$\Delta^I \setminus C^I$	Does not have a diagonal bracing member not (hasComponent some DiagonalBracingComponent)
Top concept	Δ^I	Domains (intersection) of R^I is C^I Description: hasComponent Domains (intersection) Scaffolding
Bottom concept	$\varnothing$	Ranges (intersections) of R^I is D^I Description: hasComponent Ranges (intersection) ScaffoldingComponent
Existential restriction	{x| some R^I - successor of x is in C^I }	R^I some C^I hasInterface some AttachedModuleInterface
at-most restriction	{x| at most n R^I - successor of x are in C^I }	R^I max n C^I hasComponent max 4 ScrewJackComponent
exactly restriction	{x| exactly n R^I - successor of x are in C^I }	R^I exactly n C^I hasComponent exactly 4 LatticeGirderComponent
Nominal	$\{ a^I \}$	R^I value a^I hasComponent value Standard3200

Tabe. 1 - examples of Logical Axioms used in the scaffolding ontology

Conclusion

Issues were encountered in the final stages of implementation of the ontology in Protege, resulting in the reasoner failing. Three times the ontology was re-started from scratch, but issues persisted causing the error "individual is sameAs and differentFrom another...". It is the intention of the author to solve this fundamental error in implementation (suspect it has to do with the 'exact' restriction) and correct the ontology at a later date, thus benefiting from the lessons learned. The submitted .owl file reflects the aim of the author to implement the concepts described herein despite falling short in terms of solving the logical incompatibility between classes.

References

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