CIFE Center for Integrated Facility Engineering

CIFE Seed Proposal Summary Page
2014–15 Projects

Proposal Title: Managing Construction Parts – From Manufacturing to Construction

Principal Investigator(s): Dr. Calvin Kam (CIFE), Dr. Ben Schwegler (Disney Research China), Prof. Martin Fischer (CIFE), Dr. Cheryl Chi (Tongji Univ)

Research Staff: Helen Chen (Disney Research China); Daniel Hall, Nanyu Zhao and Sijia Tao (CIFE)

Proposal Number: (Assigned by CIFE): _____

Total Funds Requested:

First Submission?   **If extension, project URL:**
No   **http://cife.stanford.edu/SeedProjects/PartList**

Abstract (up to 150 words):

The AEC industry does not consistently design, engineer, manufacture, construct, operate or maintain buildings from an integrated information platform. This results in a loss of efficiency and rework from design through operation stages. By adopting the advanced practice found in manufacturing and aerospace industries, this Seed Proposal intends to further develop the concept of "Parts" as the first step toward an integrated information platform in construction. Common understanding and knowledge about Parts between participants lay down the foundation of improving building process towards an assembly operation. The Information related to Part supports a lean supply chain management, and provides better evaluation on the value of design iterations. A fully developed Part Ontology and its application will allow for a more efficient, collaborative, and data-driven decision-making process in the industry.

1.0 Motivating Engineering / Business Problem

To date, the majority of Virtual Design and Construction (VDC) efforts have applied innovative technological and process methods such as Building Information Modeling (BIM) and lean methodology to improve the visualization, integration, and efficiency of the existing Architecture, Engineering and Construction (AEC) industry framework. Yet despite these advances, the AEC industry still remains highly fragmented. The AEC industry does not consistently design, engineer, manufacture, construct, operate or maintain buildings from an integrated information platform. Practitioners lack the resources and information to effectively generate and communicate decision factors (Kam 2004).

1.1 Typical Industry Problem

One industry study case could demonstrate that without integrated information platform, even the best design team may find it difficult to make design decisions which satisfies multidisciplinary requirements. A typical example is provided by a large project with multinational stakeholders and extensive use of BIM and VDC applications. The project has a special designed window trim and cornice (Figure 1) to fit with the overall style of the building. Originally the trim and cornice were specified to be made of fiberglass reinforced plastic (FRP); the material schedule was even specified in the supplier's details. Nearly two years later, the design team received the information that FRP cannot be made into the special shape of the cornice at that time. The design team eventually modified the trim and cornice to be made from more expensive glass-fiber reinforced concrete (GRC) and selected new supplier for the GRC material.

Figure 1: A Similar Window Detail in Brussels, Belgium

The material of other trim and sills were changed as well, in order to balance the increased cost of using GRC instead of FRP. In this case, better information about product behavior (like constructability of window cornice) provided during early decision making stages would save significant design rework, provide a more accurate cost estimation, and align the project with a supplier earlier in the project.

The above example demonstrates several common problems in the construction industry. First, the potential exists of significant rework during design process. Each product needs to go through multiple cycles of iteration around the designer, engineer, and contractor until the product acceptable to all participants

is selected. Second, information is documented in various locations and is often scattered. At the end of design and construction process, product information is often lost or separated in multiple documents and various forms between different stakeholders and cannot be effectively compiled for use during the operation and maintenance (O&M) stage of the building. Third, information is not available in a machine interpretable format and prevents the design team from using a data-driven approach to select the best product for the life cycle performance goals of the project.

1.2 Product, Organization, Process

To further summarize, the fragmentation problem is apparent across the three categories of VDC: Product, Organization, and Process (Kam 2004).

1.2.1 Product

Product information for a construction project is represented in several different forms. Traditionally the industry represents product data through a combination of 2D drawings separated by discipline and a set of design specifications typically organized using a work breakdown structure (WBS) such as MasterFormat. Product details are represented using submittals and contractor shop drawings. Product costs and productivity rates are represented using cost estimates. The use of VDC has emerged to virtually represent the geometries of products. Product modeling tools such as Autodesk Revit or Trimble Tekla virtually model the physical components or features of an object (Kam 2004). COBie is used to represent the O&M phase of construction. As builts are used to represent the final construction locations of the project. All of this product information is created, stored, and recalled across different platforms.
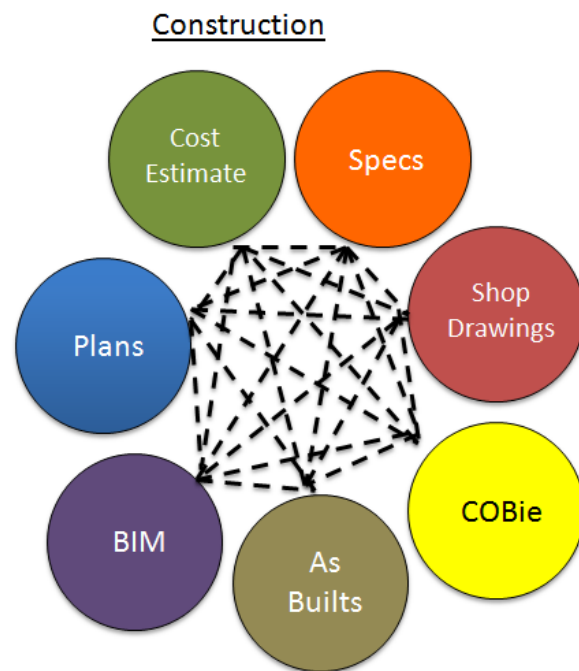

Figure 2: Construction Product Data Web

1.2.2 Organization

However, there is a fundamental difference in the requirements of virtual object representation for design, engineering, construction, and operations. For example, engineering disciplines

are not always able to leverage the 3D object intelligence for tasks such as thermal analyses. Construction disciplines are not able to leverage the 3D object representation for quantity takeoffs when the virtual object does not accurately portray the physical object that will be installed during construction. As a result, industry practitioners engage in silo-based decision-making. Because information relevant to all disciplines is not always available, practitioners often make decisions that do not consider the impact on all relevant stakeholders.

1.2.3 Process

A large amount of project information is lost between stages of a project. The standard industry workflow results in high levels of both informal and documented information loss between project stages. Large amounts of object information are lost in the translation process from design drawings to engineering calculations to product specifications to shop drawings to as-built drawings and finally to facility management systems. Each stage in the workflow requires data to be recreated to meet the needs of a project stage.

1.3 A New Ontology for Parts in Construction

This research project proposes to develop the concept of a "Part" for construction as the first step to improve the framework used to communicate information across disciplines and projects. In order to do this, we will (1) continue to develop a Part Ontology for Parts in construction, including exploration of subclassifications, (2) apply this Part Ontology to create an integrated Bill of Materials for construction, and (3) use Parts as a new metric for lean construction.

2.0 Theoretical and Practical Point of Departure

In the previous year, the research team for the CIFE Seed proposal *The Integrated Virtual Parts Library - Parts List Definition* successfully deconstructed the Disney H-1 Hotel in Shanghai. The intent was to develop a structured parts list that was dynamic, smart, and integrated. However, as the team began to consider the necessary requirements for such a list, a more fundamental question arose: What is the definition of a "Part" for Construction?

2.1 Operational Definition

As described by the Stanford Encyclopedia of Philosophy, Operationalism is based on the intuition that the meaning of a concept is unknown unless it has a method of measurement (Chang 2009). The current AEC industry's understanding of "parts" has little meaning because no uniform definition exists to

consistently measure the concept. To solve the problem of operationalism for a part, an operational definition must be created to define the object in terms of a process or set of validation tests in order to determine its existence and quantity. The research team created the following operational definition for a part:

> *A part is any entity that requires an on-site construction activity to install in its permanent location.*

2.2 Part Count

Using this operational definition, a seven-member research team worked for 6 months to create a comprehensive part count estimate for a construction project. Walt Disney Imagineering provided the team complete access to the Disney H-1 Hotel project in Shanghai, China. The Disney H-1 Hotel is a seven floor, 420-guest room hotel in the early construction stage for the Disneyland Resort project in Shanghai. The gross floor area is approximately 40,000 square meters. Disney provided the research team full access to BIMs, specifications, shop drawings, cost estimates and work breakdown structures.

The research team deconstructed the existing BIM and exported a complete list of virtual artifacts. In total, the BIM represented 110,000 virtual artifacts, of which 98,000 were physical artifacts and 12,000 were analytical artifacts (such as grid lines, room tags, etc.). These 110,000 artifacts are organized into 100 categories which are referred to as families by Revit. For example, all the virtual door artifacts found in the BIM would be considered one family. Altogether the 110,000 artifacts contained 1,147 unique attribute categories (such as height, thickness, color, etc.).

The research team next attempted to count the number of parts manually. Using a combination of BIM deconstruction, project shop drawings, and information from the project team, the team developed a minimum and maximum part count for five building systems: Substructure, Shell, Interiors, Services, and

System	Minimum Count	Maximum Count
Substructure	140,000	240,000

Shell
    Superstructure
    Façade
	910,000	1,400,000

Interiors
    Interior Construction
    Finishes
	1,700,000	2,500,000

Services
    Mechanical
    Plumbing
    Electrical
	430,000	440,000

Other Equip & Furnishing	88,000	90,000
Total	3,268,000	4,670,000

Other. Using these manual counting methods, the Disney H-1 project numbers between 3.2 million parts and 4.8 million parts, depending on the assumptions for the level of prefabrication. Given the building floor area, this results in an average of 98 parts per square meter.

2.3 Bill of Materials in the Manufacturing Industry

The manufacturing and aerospace industries, among others, have adopted the concept of a Bill of Materials (BOM). A BOM is a formally structured list for an object which lists all the component parts of the object with the name, reference number, quantity, and unit of measure of each component. Modern manufacturing generates parts lists to identify the quantity and type of interchangeable components required to manufacture a certain product.

Lean manufacturing operations developed by the Japanese, such as The Toyota Production System (TPS), begin with a complete BOM. The operation then uses the concept of Just in Time (JIT) to produce and deliver the right parts, in the right amount, at the right time using the minimum necessary resources. Western manufacturing built upon the Japanese system with the development of Design for Manufacture and Assembly (DFMA). DFMA provides "systematic methods for standardizing designs of component parts and simplifying and reducing the costs of manufacture and assembly of products and components." (Schonberger, 2007). Four of the six design DFMA principles deal with parts: minimize the number of parts, design for ease of Handling, design for ease of insertion, and standardize parts (Molloy et al., 1998)
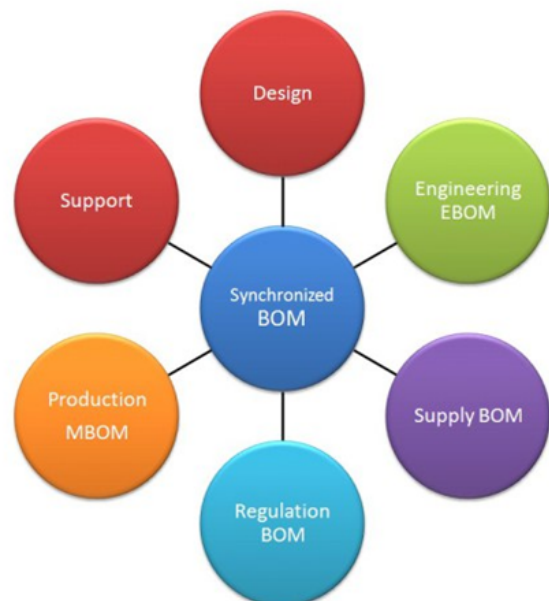
(Source: PLM Think Tank website)

2.4 The Value of a Part

A recent BBC article highlights the level of attention given to Parts by the aerospace industry. Airbus knows it has 6 million parts in the A380. Furthermore, Airbus is diligent about reducing the weight of its planes by combining parts, saying "each kilogram saving in weight can save roughly $1m (£603,000) in costs over the lifetime of an aircraft." Airbus is looking to reduce the number of parts by

using composites such as carbon fiber which will greatly reduce the number of parts and can reduce the weight of an aircraft by up to 20% (BBC news, 2014).

2.5 Prefabrication & Lean Construction

More companies are using prefabrication today, and a project with advanced prefabrication practice will result in a Part reduction by an order of magnitude. The Seed Project team studied the case of prefabricated bathrooms in a hospital project. The results find that with the help of prefabrication, the Part count for one bathroom could reduce from 4,000 to about 60. For a total of 440 bathrooms in that project, the Part count is cut from about 1.7 million to 25,000, which is a 98.5% reduction in total number of onsite parts. This prefabrication also resulted in 7 months of schedule saving, 150,000 hours or work moved from onsite to off-site, and about 3% overall cost saving. It is clear that there is a lot benefit in promoting prefabrication and a relationship between Part number and cost and schedule saving could be generated. The study case further validated the potential benefit of this Seed Project.

The Construction Productivity Index from Paul Teicholz revealed that the productivity for non-farm industry, especially manufacturing industry, kept rising over the last forty years; yet the construction productivity was decreasing. While many reasons many cause this situation, this Seed Proposal plan to demonstrate how the creation of a Part list for construction will help the building process evolve from craft to assembly operation. The use of Part is the first step of matching design to the assembly workface. Once the complete ontology is established, the Seed Project team will recommend using "part" as base of the integrated information platform between project participants and across projects, leading to an organized and efficient construction process.

3.0 Methods

In the last year, the IVPL - Parts List Definition research team managed to: (1) demonstrate the limitation of current practice; (2) highlight that an organized, integrated, and dynamic information platform is necessary; (3) propose the concept of Part as the base of this platform; (4) work on industry study cases using the preliminary Part Ontology. Based on previous study and many helpful feedback collected from industry workshop, the future study of this Seed Project will focus on three major points.

3.1 Continue to Develop Part Ontology

Working closely with industry case studies provided by CIFE members, the research team plans to further refine the operational definition of a Part and

its relevant concepts. Follow up work on the existing Disney H-1 hotel case will be carried out, including creating detailed result documentation for future reference. In addition, another office renovation project will be studied. This work intends to create a more accurate Part count, including Part number, Part type and Part category breakdowns. The team plans to generate a BIM using the collected part and evaluate its efficiency in communicating between participants. The research team will also collect data from other leading VDC projects to estimate the number of parts. With all available data, research will focus on the variance or consistency in Part count across different projects, and the further categorization of the Part definition. The further developed Part categories will contain multi-dimensional parameters, covering the needs from different construction trades. This study will create an ontology classification for every type of Part in one of the study cases, by which the study would like to propose a better developed Part Ontology diagram (Figure 3) as the foundation for future work.
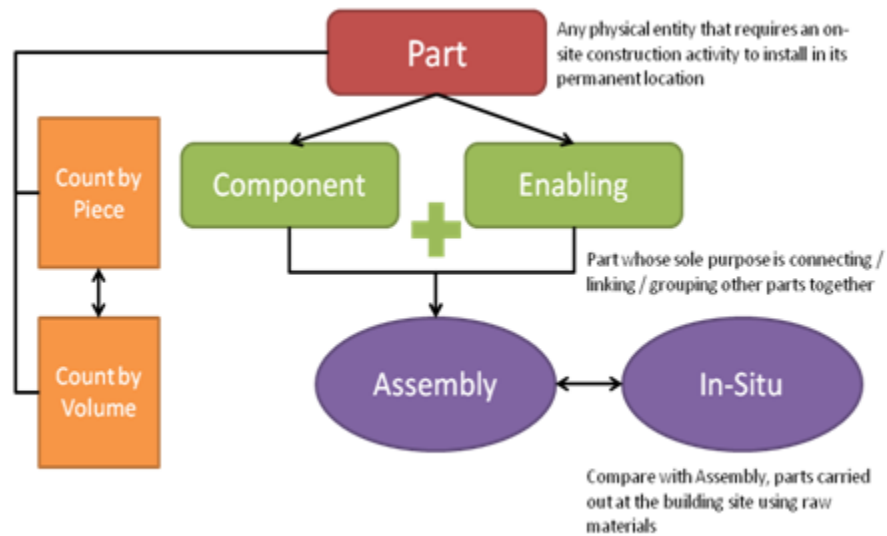

Figure 3: Current Part Ontology Diagram

3.2 Apply Part Ontology to Develop BOM

Building upon the use of BOM by manufacturing and aerospace industries, this research will further investigate the adoption of BOM for the construction industry. First, we will assess the effectiveness of BOM for sophisticated manufacturing products, understand the information flow within manufacturing, and summarize the criteria of a successful BOM in the manufacturing industry. Next, we will look at how to apply BOM to the construction industry. We will look to partner with several innovative construction firms such as DIRTT, Aditazz, or Bone Structure who have begun to apply the BOM concept to projects.

Using a developed Part Ontology and lessons learned from BOM investigations, the Seed Project team plans to create a draft BOM for an office

renovation project already agreed to be provided by a CIFE member. Detailed information will be collected from industry interviews and process observation through the project. The draft BOM will hold Part information about the form, function, and behavior of the Part, across the design, engineer, manufacture, construct, operate and maintenance stages of the project. The team will then use this draft BOM to critique and comment on both the current construction information exchange practice and the proposed Part Ontology, and to highlight the important criteria in generating a BOM for a construction project.

3.3 Use Parts as New Metric for Lean Construction

The Part Ontology intends to change the way industry views BIM artifacts. Because a part remains the same in different locations and different projects, this Seed Project aims at proposing Part as new common denominator in construction industry. One important implication is the capability of Parts to become a new metric for lean construction. Because we recognize that to verify predicted impacts could take rather long time and requires various projects as a data source, we plan to focus on two of the many applications in this coming year. One is using Part number as an indicator of prefabrication rate. By analysing the broader scope of Part number (including intermediate Part, temporary Part, and off site Part), it is believed that a good project, with less cost and shorter schedule, would be a project with higher percentage of prefabricated Part and a broader Part count within certain range. In this way a good understanding of Parts would help the project team to better quantify the benefit of prefabrication. Another application is using the Part to estimate the impact of design iterations. The MacLeamy Curve (Figure 4) indicates that the later a design change is made, the higher it will cost. However, a quantitative relationship between a design change and its impact is still not clear. We intend to quantify this relationship using parts; We can understand the total number of Parts affected by design change and the estimation of the cost per Part to predict the impact of design iterations. This will help project team to quickly estimate the feasibility of design iterations, quantify the its impacts and select the best design option with more confidence.
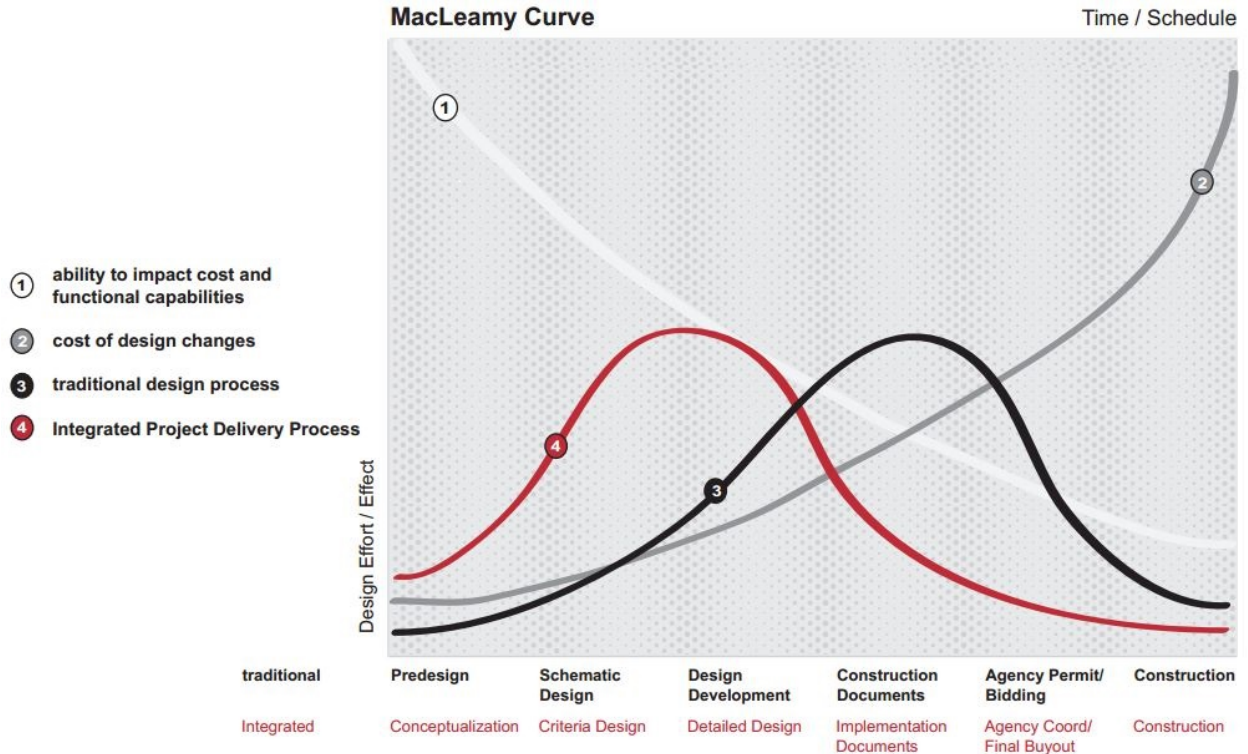
Figure 4: MacLeamy Curve
http://www.msa-ipd.com/MacleamyCurve.pdf

Many other potential applications will be found and evaluated during the research, making the Part concept more useful to the AEC industry.

4.0 Relationship to CIFE Goals

This Seed Project will contribute to the broad CIFE vision of improving VDC. Specifically, it will improve the AEC industry through increased effective of communicating through BIM. The Parts Ontology will use the Product, Organization, Process model of CIFE and align with CIFE's research focus and breakthrough performance objectives.

The Part Ontology will encourage AEC stakeholders to make better decisions in regards to the exact product that goes into the building. By focusing on the final construction activities, it reduces the chance of making rush decision with incomplete knowledge and enable a streamlined decision-making process. This lean design process will have better schedule performance with reduced redesign and delays. As cost data is incorporated in Part information and will be leveraged during the early stage, the risk of overshooting target budgets is reduced. In addition, the life cycle parameters of building Parts, including their predicted and actual behavior, will be evaluated by multiple stakeholders to

maximize opportunities to advocate sustainable performance. More importantly, Parts will be identical in different projects across the world, making it easy to share experience, compare data, evaluate performance and adopt the Part logic across projects and borders.

The expected Part Ontology applications will also support the CIFE breakthrough performance objectives. It is noted that Part could serve as metric for lean construction, enable better construction process management and better evaluate of value-adding activities across the global AEC community. It is expected that in the future, the Part count and Part information will be automatically generated from BIM, allowing the interpretation and use of large volumes of data in the project's life cycle.

5.0 Industry Involvement

Continuing the successful partnership from the past year, this study is proposed as a collaboration between Stanford University, Walt Disney Imagineering (WDI) Disney Research China, Tongji University and other Shanghai universities, and industry collaborators.

5.1 Disney Research China

Disney Research China, part of the research and development group of the Walt Disney Company, is establishing a new research laboratory in Shanghai, China. The Shanghai laboratory will focus research on Sustainable Design and Engineering and the interaction between the natural and built environments. Walt Disney Imagineering also is focusing development on lean design methodology and computational tools such as BIM and VDC. Because the goals of the Part Ontology lines up with those of Disney Research China, WDI has been an active member driving this research, providing CIFE researchers access to the WDI projects and experiences in both US and China.
Since last year, Disney Research China has been supporting research assistants from Stanford and Shanghai to work on the Seed Project. Its Shanghai lab provides the Seed Project team with great working environment and valuable construction project information. The funds provided by Disney, if augmented by CIFE funds, will help continue the research into next year and beyond.

5.2 Tongji University and other Shanghai Universities

Disney and CIFE will collaborate with researchers from Tongji University and other universities in Shanghai, China on the Part Ontology study. These researchers have been working on the Seed Project since the summer of 2013, and the team is still growing. Their work helps Stanford researchers maintain a

close connection with Disney Research Lab during the university quarters. This research collaboration accounts for the cultural and professional diversity in AEC practice between the United States and China.

5.3 Other industry collaborators

A CIFE member workshop in March 2014 introduced the New Ontology for Parts in Construction. The Stanford researchh team connected with multiple CIFE members interested in this research. McGraw Hill and Additazz have discussed additional opportunities to test and refine the operational definition for a part. Professor Calvin Kam and Professor Martin Fischer have been involved in many CIFE member organizations and their expertise with BIM in the construction industry will also be highly leveraged. Additional engagement will come through Stanford Class CEE 112/212 A, B and C Industry Applications of Virtual Design & Construction; Stanford students will be able to participate in this Seed Project through the class.

The project team will also work with any interested CIFE member or industry contacts that wish to be involved with the seed project research.

6.0 Research Plan, Schedule and Risks

6.1 Schedule and Milestone

Research for the Part Ontology is currently in progress at both Stanford and Shanghai. Currently Stanford researchers are focusing on ontology development and POD study while Shanghai researchers are engaged with WDI study cases. Some of the major milestones and schedule are summarized below:

Schedule / Tentative Deadline	Task / Milestone
June 2014	Initial Preparation; Study on previous and new industry case; Document existing results;
July to Aug. 2014	Summer internship in Shanghai; Research on BOM; Further categorize Part definitions; Part count on new study case; Create BOM for study case
Sep. 2014	**Milestone** **Part Ontology diagram and Draft BOM**
Sep. to Dec. 2014	Create BOM for study case , Summarize criteria of

	successful BOM; Research on Part applications
Jan. to Mar. 2015	Critique and comments on current construction practice and Part Ontology
Mar. 2015	**Milestone** **Industry workshop**
Mar. to June 2015	Continue build framework of BOM for construction project based on Parts; Apply for additional funding to further the research
June 2015	**Milestone** **Journal publications**

6.2 Risk

Based on last year's experience, the potential risk for the Seed Project includes lack of critical information, which leads to slow progress, rough assumptions and low confidence during the study. However, these risks will be offset because of the previous experience gained by the research team over the last year. In addition, the WDI can provide more detailed information on the new study case, so a more accurate result could be expected.

Another risk is that the project has limited study cases. Additional VDC projects are very important in providing more convincing results, yet the team has limited access and time to analyze these projects. To mitigate this risk, the Seed Project team plan to look at rough estimations of other projects in terms of their Parts count, category, type and basic information such as project scale, budget, and schedule. The team will study their trends and differences to verify the proposed Parts application without spending too much time to manually determine the part count.

7.0 Future Work

Last year's Seed Project study confirm the initial intuition: the AEC industry requires an integrated information platform to better serve the project needs. Should the research in this coming year successfully demonstrated that Parts could serve as the foundation of this integrated platform, the project team will seek additional funding to expand the proposed part ontology into a framework of BOM for construction project based on Parts. Further study on other applications

of Parts will also support the use of Part Ontology in construction projects. The project team will undergo several iterations of testing and feedback to determine if the Part Ontology and BOM framework suit different construction projects. Once determined ready, the project team will seek partnerships with CIFE members, professionals, and technology vendors to establish the integrated information database of Parts that can be used in the AEC design process.

8.0 References

Kam, C., & Fischer, M. (2004). Capitalizing on early project decision-making opportunities to improve facility design, construction, and life-cycle performance—POP, PM4D, and decision dashboard approaches. *Automation in construction*, *13*(1), 53-65.

Figure 2: A Similar Window Detail in Brussels, Belgium. https://flic.kr/p/6rDJbu

Chang, H. (2009). Operationalism.

Sijia Tao (2012). BIM parts library. CEE 212B

Mark J. Clayton, Paul Teicholz, Martin Fischer, John Kunz (1999). Virtual components
consisting of form, function and behavior. Elsevier Science B.V.

Toyota Production System http://artoflean.com/tps_history.htm

Schonberger, R. J. (2007). Japanese production management: An evolution—With mixed success. Journal of Operations Management, 25(2), 403-419.

Molloy, O., Tilley, S., & Warman, E. A. (1998). Design for Manufacturing and Assembly: Concepts, architectures and implementation. Springer.

Carbon fibre planes: Lighter and stronger by design
http://www.bbc.com/news/business-25833264

Figure 4: MacLeamy Curve http://www.msa-ipd.com/MacleamyCurve.pdf