# Applying a System Engineering Approach to the Early Stage of Product Design

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ABSTRACT: The purpose of the study is to equip product designers with a holistic system view by applying a system engineering approach, Object-Process Methodology (OPM) pairing with a design thinking process, to the early stage of the product development. The study demonstrates the implementation value and conceptual system modeling feature of OPM through the product design case study, which presents its potential application of Model-Based System Engineering (MBSE) language and framework for the complex challenges by applying system thinking and design approach.

Keywords: Systems Engineering, System Design, Product Design, Design Methodology, OPM

## 1. INTRODUCTION

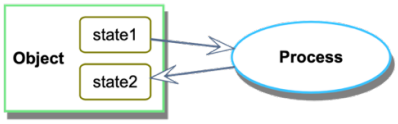
In the era marked by exponentially faster change, most design challenges have become complex and naturally have involved diverse perspectives, stakeholders, frameworks, and methodologies during projects. Therefore, only applying the typical product design and development process (IDEO Product Development, 2003) to systemic challenges does not address the problems holistically. We conducted an experiment by curating Object-Process Methodology (OPM), a Model-Based System Engineering (MBSE) language, with the selected phases of the product design process: ideation phase, prototyping phase, and testing phase (Ulrich et al., 2020) to refine and improve the methodology. The study explored the potential roles and functions of system engineering in the design process by integrating the MBSE framework to establish a comprehensive and creative new process.

## 2. METHODOLOGY REVIEW

### *2.1 Object-Process Methodology (OPM)*

Object-Process Methodology (OPM) is a model-based language that originated in the field of system engineering to describe systems ranging from product manufacturing systems, technological systems, social situations, socio-technical systems, natural phenomena, and other complex systems through three fundamental pillars: Object, Process, and Link (Dori and Crawley, 2013). OPM is one type of MBSE language recognized by ISO as ISO-19450, which became a globally standard conceptual modeling methodology. It has already been applied to various industries to describe a complex system in both a graphical and textual way by demonstrating the structural relationships.

Table 1. OPM Element Definition (Source: OPCloud Manual Version 2.0 Guide, 2019)

| Element | Object | Process | Link |
|---|---|---|---|
| Definition | Objects are things that exist over time and can be either physical or informational. Objects can also have different states. | Processes are things that transform Objects by creating them, destroying them, or changing their states. | Links connect Processes with Objects to express these transformations and to form the meanings of the connections. |
| Example |   | | |

*2.2 System Diagram (SD)*

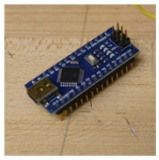
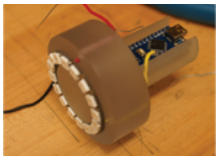
The System Diagram (SD) serves as the canvas for OPM, which defines the purpose, scope, and main functions of the system in terms of its objects, processes, boundaries, and stakeholders ("OPCloud Manual Version 2.0 Getting Started Guide," 2019). The purpose of the SD is to provide a bird's eye view with minimal technical detail for the key stakeholders to clarify the main functions and identify the core benefit of the system. The SD contains two levels: level 0 and level 1. While the system extends and becomes complicated, SD1 (level 1) comes into play to describe the system's structure, behavior, and function. SD1 is a descendant of SD. The supplement information of SD1 makes SD comprehensive and complete. Figure 5 and Figure 6 show the relationship between the two layers.

## 3. THE MODULAR LAMP CASE STUDY

It was a 4-week design sprint case study and two intentions:

- **Integrate System Thinking into Design Process**. It evolves the traditional creative process from "Apply human-centered process to solve product-related projects" to "Use design thinking approach by combining system thinking framework to tackle with complex-yet-systemic challenges."
- **Unlock the Creative Potential of Participants**. It transforms participants' perception from "Participants are afraid of making mistakes" to "Encourage the participants to enjoy the creative process." It changes the game rules from "Tell the participants the answer" to "Empower the participants to explore the possibilities."

Table 2. Modular Lamp Material List

| Item | Joint Connector | NANO Board | T-shaped Base Holder | LED Ring Light | Used Water Bottles |
|---|---|---|---|---|---|
| Spec or Materials | 3D printed material (PLA) | ATmega328P 5V 16M Micro-Controller Board | 3D printed material (Photosensitive Resin) | 16 Bits LED Ring Lamp Light | VOSS Water |
| Number | 7 Types | 1 Unit | 1 Unit | 1 Unit | 20 Units |
| Photo |  |  |  |  |  |

*3.1 Design Process – Ideation, Prototyping, and Testing*

The case study was composed of two main sections (Figure 1). The first section was the Design Process which included ideation, prototyping, and testing. The second section was to apply OPM for the purpose of refining the overall product design. In the ideation phase, design approaches including sketches and paper mock-ups were applied. In the rapid prototyping phase, selected ideas were translated into CAD for 3D printing, which gave the design team a more precise yet tangible mock-up to refine its design before entering the testing phase.

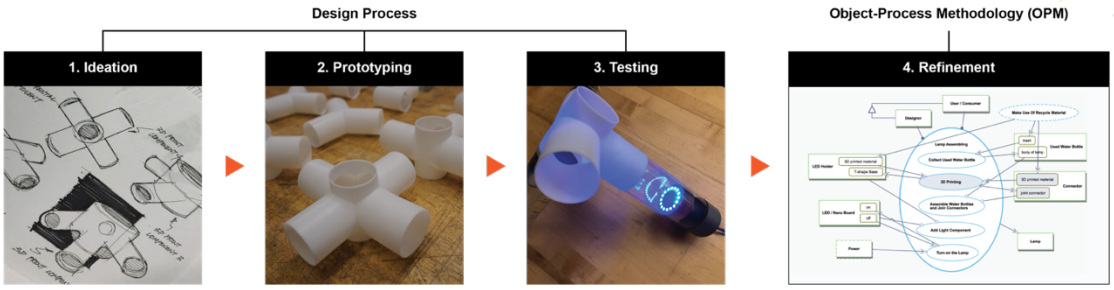



Figure 1. The Product Design and Development Process of the Case Study – Modular Lamp

The following phase in the case study was to test the prototype (Figure 2). It came with multiple possibilities to assemble the modular lamp with different configurations (Figure 3 and Figure 4). While the modular lamp design moved into the next step of refinement phase, OPM was applied to the design process as an experimental approach to revisit the overall product design process.

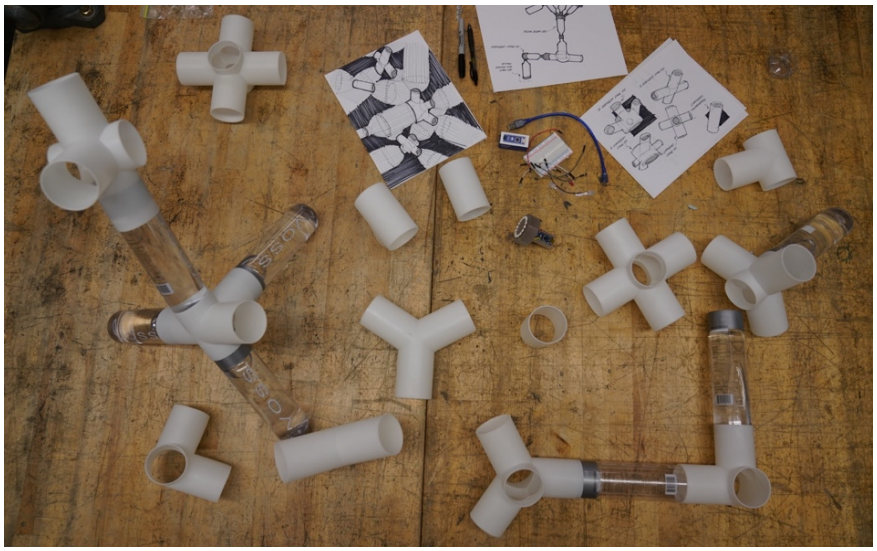


Figure 2. Assemble the design components

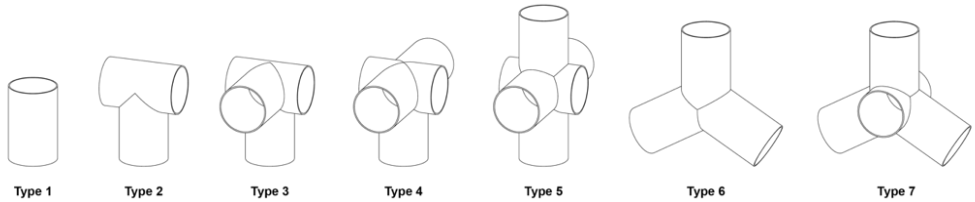



Figure 3. Seven Types of Joint Connectors

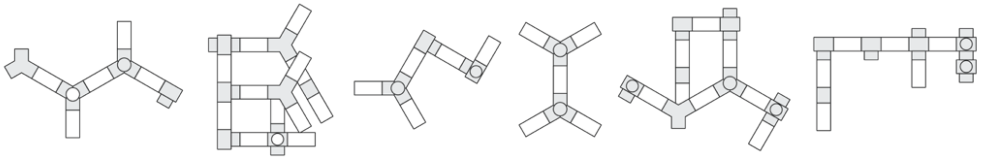


Figure 4. Different Configurations (White: Used Water Bottle; Gray: Joint Connector)

*3.2 Design Highlight – Product Refinement by Using OPM*

The case study started from the ideation phase, rapid prototyping, to model testing for section one of the design process. The refinement phase was the section where OPM was applied to revisit the modular lamp design on the system level. The first step was to define and decompose the elements of the modular lamp and categorize them into components: Object (Lamp, LED Holder, NANO Board, Connector, Used Water Bottle), Process (Lamp Assembling), Instrument (Power), Agent (Designer, User/Consumer), and Environment.

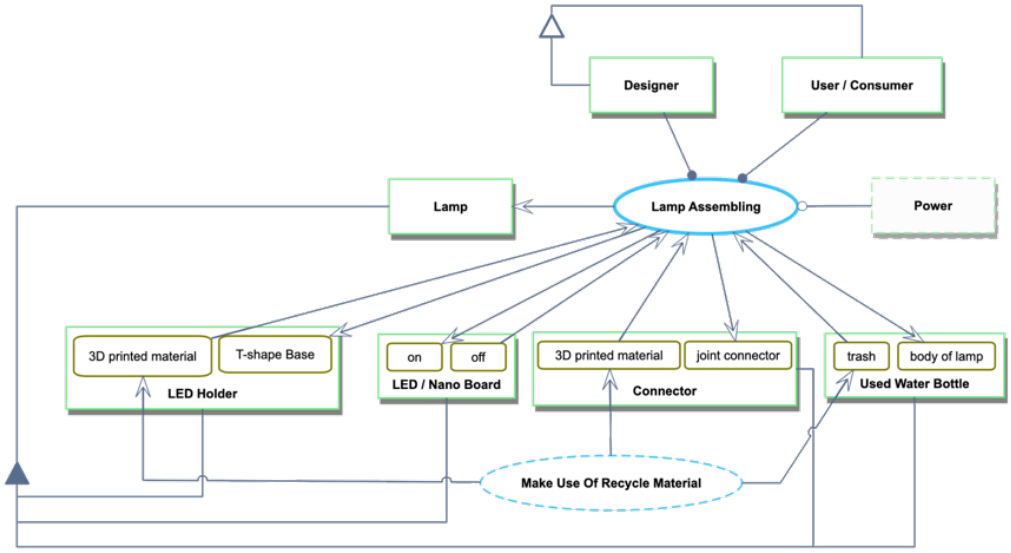



Figure 5. System Diagram (SD) Level 0 of the Modular Lamp Design

In the case study, the modular lamp project applied two levels of SD to describe the structure and the interface of the system. SD1 (level 1) was defined as Assemble Lamp with its sub-process including Collect Used Water Bottles, 3D Printing, Assemble Water Bottles and Joint Connectors, Add Light Component, and Turn on the Lamp (Figure 6).

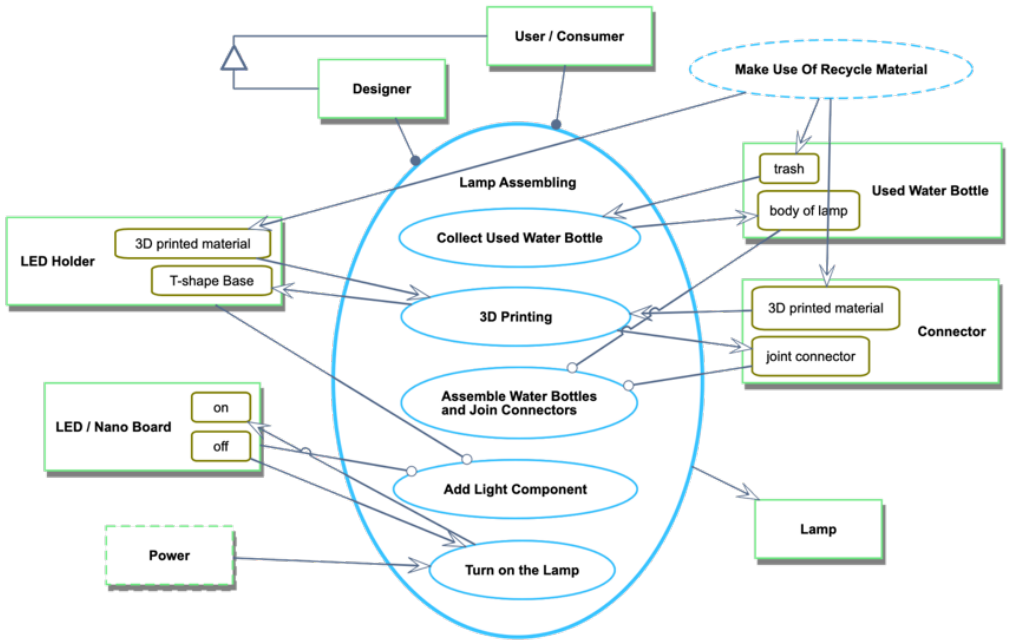



Figure 6. System Diagram (SD) Level 1 of the Modular Lamp Design

The intention was to apply OPM in combing with the product design and development process to obtain a comprehensive perspective to re-examine its system architecture and to develop a product development strategy and blueprint in advance. In this case study, the following system-related how-to questions were triggered by leveraging SD and SD1 of the modular lamp design e.g., How to reshape the design and the model of the seven types of Joint Connectors in order to make diversified configurations of the lamp structure in response to the system transformation? How to design a set of criteria to evaluate the performance of the modular lamp system? (Crawley et al., 2004) The how-to questions were examples inspired through SD (Figure 5) and SD1 (Figure 6). They facilitated the team and key stakeholder's discussion around how to make an existing system resilient, establishing capabilities and flexibilities for future challenges.

## 4. THE SUMMARY OF THE CASE STUDY

- **Examine the Critical Components within the System.** In general, the design-related project will become complex as the process of development moves forward. Therefore, there are more aspects e.g., product components, stakeholders, manufacturing, policy, marketing, and other relevant elements that need to be taken into serious consideration. OPM can efficiently categorize the components into either Object or Process through the lens of the system level, which effectively assists the project team to identify the critical components and their relationships to clarify the major problems within the system.
- **Adopt a Holistic View to Revisit the Relationship.** The System Diagram (SD) of the project gives OPM its platform and meaning by utilizing OPM Links to connect the Objects and the Process in the system. SD provides a bird's eye view to examine all relationships to help the project team foresee the possibilities to plan other connections by predicting and analyzing its system pattern to prevent unstable system conditions and environment.
- **Extend the Flexibility and Fluidity of the Project Development.** A typical product design and development approach is a relatively linear process from ideation, prototyping, testing, refinement and manufacturing, which partially limits the flexibility and fluidity of the project development in the face of urgent conditions e.g., the shortage of the budget, the transformation of the organization. OPM is applied to model the conceptual system to simulate multiple scenarios and to adjust its connections and structures between the Objects and the Process in the system according to different situations and criteria, which increases the adaptability of the system (Crawley et al., 2004) to improve the flexibility and fluidity of the project development.

## 5. CONCLUSIONS AND DISCUSSION

- **Provide a New Meaning of the Sketching in Product Design and Development.** OPM is a collaborative tool to sketch out the model of the product design and development process covering Objects (forms), Processes (functions), and Links (relationships) in the macro views of a system, which is complementary with the relative micro view adopted by using sketching, a typical product design skill that forms focus features of the typical sketch tool, to explore the form and aesthetic part of the design. It redefines the meaning of sketching in the context of OPM.
- **Reconsider the Product Design and Development Process in a Broader Context.** In the era of transformation, product design and development need to reposition their process and criteria to evaluate the performance and structure of the project. How to adapt the system thinking and its framework to the product design and development process? OPM is one system engineering approach applied to the study as an experimental tool. There will be more opportunity areas to leverage the hybrid methodologies to solve complex challenges.

Future research can explore the best moment and condition to apply OPM for the purpose of system model prototyping, Object-Process relationship identification, and critical form-and-function clarification in the context of the product design and development process and other relevant MBSE languages and frameworks beneficial to the process.

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