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# APPLICATIONS OF AXIOMATIC DESIGN IN THE PROJECT MANAGEMENT OF NEW PRODUCT DEVELOPMENT – A LITERATURE RESEARCH

BY

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**Abstract.** The article investigates the applications of Axiomatic Design to the Project Management of new product development as it currently stands based on publicly available materials. Project Management is a collection of processes tailored to fit an application. The research focused on processes associated to Project Management, and it was less focused on product design. The results of the investigation indicate that the application of Axiomatic Design to Project Management would be useful and would lead to improvements of projects' success and business's Return-on-Investment. The researcher concludes that product requirements could be used to model a uniform approach to most processes used in Project Management but, depending on the project complexities, a smaller scope approach is more appropriate depending on company's internal organization of work. It will be beneficial to either project management practitioner or any business manager to have a framework easy to utilize in designing processes as needed for the successful completion of any project.

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## 1. Introduction

Throughout history, humanity has been involved in developing new products to improve society's living conditions, mostly done at commercial level. To improve their profitability, businesses undertake activities related to the development of products and services offered to their customers in such a way that they translate into a positive return on investment. These activities are continuous, mass, batch, job or project type. Project-based activities are performed to obtain a specific result, such as a product, a service, or a process (Greasley, 2008).

A product is characterized by meeting customer needs (CN), providing needed functional requirements (FR), as well as innovative design parameters (DP), while using best process variables (PV) (Lu and Liu, 2016). Product lifecycle includes phases such as: introduction, growth, maturation, decline and death (Ariss and Zhang, 2002). In 1979, Hayes and Wheelwright (Hayes and Wheelwright, 1979) introduced the concept of product–process matrix that shows how manufacturing (processes) and marketing (products) are connected.

To develop a product, the companies follow a systematic approach through a series of activities known as New Product Development (NPD). NPD includes phases such as discovery, screening, conceptualization [design, prototyping, and manufacturing], road-mapping, and launch (Bigliard *et al.*, 2013). In 1990 R.G. Cooper (Cooper, 1990) introduced the Stage Gate model for managing new product development processes, which since then has become the most popular model used in industry. The flow of Stage gate processes are as follows: discovery [idea generation], scoping [of the project], business case [product definition, project justification and plan], development [detailed component design and prototyping], Validation [market testing and operations trials], and launch [commercialization]. Each of these phases is followed by a stage named "gate" in which the decision to continue the process is taken. The Waterfall methodology is a very popular methodology that has been coined by W.W. Royce (Royce, 1970) in the field of software development. The Waterfall approach is divided into sequential phases such as analysis, design, implementation, testing, and maintenance. (Bell and Thayer, 1976; Senarath, 2021). Each of these phases can be treated as independent projects. PMI has formed a set of guidelines on the processes to be followed to achieve the desired results. (PMI, 2017) Product management and project management are not identical, although they do overlap in certain areas. They mainly differ in their scope: product management is mostly focused on marketing aspects, while project management is mostly focused on organization of activities (Demirel and Camcı, 2022).

The best utilization of a business' resources is obtained through optimization of processes as well as of products. Many problem analysis methods can be used for either product or process or both. The most popular ones are Axiomatic Design (AD), Quality Function Deployment (QFD), and Total Quality Management (TQM) (Wang *et al*., 2017).

The presented paper will focus on Axiomatic Design (AD), Project Management (PM) and how AD can be applied to PM processes.

## 2. Discussions

### 2.1 Project Management processes

The activities undertaken to create unique results are typically referred to as a project. Project Management Institute [PMI] defines projects as temporary efforts to create value through unique products, services, and processes, through the project development life cycle which includes phases such as initiation, planning, execution, controlling and closing, regardless of the phase of the product lifecycle (introduction, growth, maturity, decline) (Pessoa and Trabasso, 2017; Udokporo, 2021). PMI identifies 5 process groups (Initiating, Planning, Executing, Controlling, Closing) and 10 knowledge areas (Integration, Scope, Schedule, Cost, Quality, Resources, Communications, Risk, Procurement, and Stakeholders). Table 2 depicts the main processes associated with Project Management Process Groups and Knowledge Areas.

According to the Project Management Institute there are 5 process groups and 10 knowledge areas. The process groups include the initiating, planning, executing, controlling and monitoring and closing processes. The knowledge areas include as it follows:

1. Project integration management
2. Project scope management
3. Project time management
4. Project cost management
5. Project quality management
6. Project resource management
7. Project communications management
8. Project risk management
9. Project procurement management
10. Project stakeholder management

**Table 1**

*Project Management Process Groups and Knowledge Area*

| *Knowledge Area* | *Process Groups* | | | | |
|---|---|---|---|---|---|
| | *Initiating Process* | *Planning Process* | *Executing Process* | *Controlling Process* | *Closing Process* |
| *Integration* | *Charter* | *Manage Plan* | *Manage Work Knowledge* | *Change control* | *Close* |
| *Scope* | | *Requirements WBS* | | *Validation* | |
| *Schedule* | | *Plan Activities* | | *Control Schedule* | |
| *Cost* | | *Budget* | | *Ctrl. Bud.* | |
| *Quality* | | *Plan Quality* | *Manage Quality* | *Control Quality* | |
| *Resources* | | *Plan Resources* | *Manage Resources* | *Control Resources* | |
| *Communications* | | *Plan Communications* | *Manage Communications* | *Control Communications* | |
| *Risk* | | *Plan Risk* | *Manage Risk* | *Control Risk* | |
| *Procurement* | | *Plan Procurement* | *Conduct Procurement* | *Control Procurement* | |
| *Stakeholder* | *Identify Stakeholders* | *Plan Stakeholders* | *Manage Stakeholders* | *Engage Stakeholders* | |

Project Management Institute. *A Guide to the Project Management Body of Knowledge (PMBOK Guide)*. 6th ed., Project Management Institute, 2017.

The flow of information in project development life cycle employs methodologies such as Waterfall, Agile, or a combination of them (Balaji and Murugaiyan, 2012). They are a sequential series of activities, Waterfall method, performed in such a way that once one activity ends the following one begins. The Agile method is less structured, and the activities can be done in parallel. The combination of these methods allows for certain tasks to be sequential, while others can be done in parallel (Palmquist *et al*., 2013).

A successful project is being affected by many factors and PMI has been developing a framework for such situations, leaving it up to the companies to make their best setup in organizing a project.

### 2.2. Axiomatic Design

In 1990, N.P. Suh (Suh, 1990) introduced, and later expanded (Suh, 1998, Suh, 2001), Axiomatic Design as a systematic approach to solving problems. The method uses a combination of axioms, domains, mapping, and design matrices to develop a comprehensive result.

There are two axioms: Independence Axiom and Information Axiom, that define the framework for systems design. The first axiom requires the functional requirements to be independent, while the second axiom requires the information content to be minimal.

There are four domains needed to separate "what" and "how" and are defined as one for each kind of design activity: Customer domain [Customer Needs, CN], Functional domain [Functional Requirements, FR], Physical domain [Design Parameters, DP], and Process Domain [Process Variables, PV].

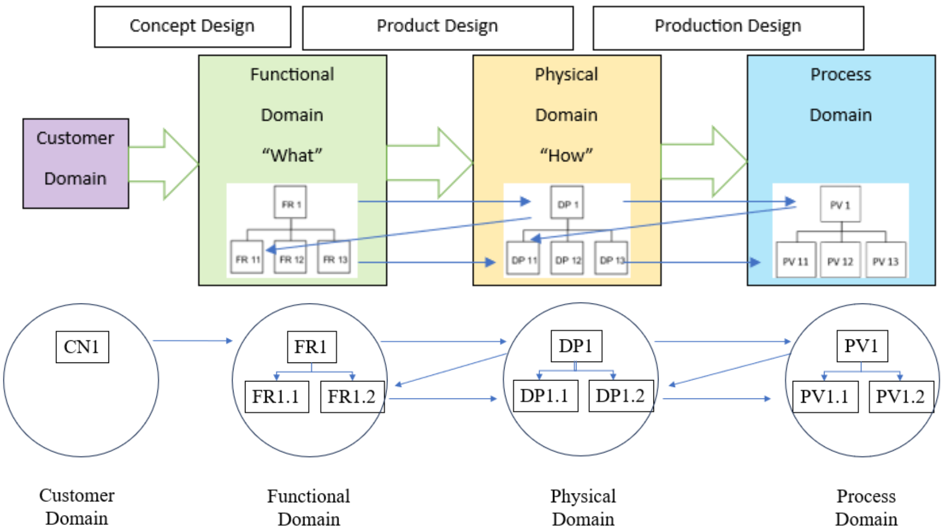


Fig. 1 – The Domains and Mapping in Axiomatic Design.

In order to decompose the design into hierarchies, the mapping between domains is done by alternating between pairs of domains and is represented by two design matrixes: a product design matrix, D, that connects functional and physical domains, and process design matrix, B which connects physical and process domains. Decisions in one domain are mapped into the other domain. The process is depicted below in Fig. 1.

The applicability of AD can be extended to various domains and vectors in industry. Some examples are shown below in Table 2.

**Table 2**

*Domains and Vector, after Table 1.1 in Suh, 2001*

| *Domains Vectors* | *Customer Domain* | *Functional Domain* | *Physical Domain* | *Process Domain* |
|---|---|---|---|---|
| *Manufacturing* | *Attributes which consumers desire* | *Functional requirements specified for the product* | *Physical variables which can satisfy the functional requirements* | *Process variables that can control design parameters* |

| *Materials* | *Desired performance* | *Required Properties* | *Micro-structure* | *Processes* |
|---|---|---|---|---|
| *Software* | *Attributes desired in the software* | *Output Spec of Program codes* | *Input Variables or Algorithms Modules Program codes* | *Sub-routines machine codes compilers modules* |
| *Organization* | *Customer satisfaction* | *Functions of the organization* | *Programs or Offices or Activities* | *People and other resources that can support the programs* |
| *Systems* | *Attribute desired of the overall system* | *Functional requirements of the system* | *Machines or components, sub-components* | *Resources (human, financial, materials, etc.)* |
| *Business* | *Return on Investment* | *Business goals* | *Business structure* | *Human and financial resource* |

### 2.3. Using Axiomatic Design

The Customer needs (CNs) or attributes are that the customer seeks in a product or system.

Functional requirements (FRs) are a minimum set of independent requirements that completely characterize the functional needs of the design solution (i.e., software, organization, etc.) in the functional domain.

Design parameters (DPs) are the elements of the design solution in the physical domain that are chosen to satisfy the specified FRs and can be easily implemented. DPs are physical parts (i.e., components, geometries), computer programs (i.e., classes, flow charts), and specifications (i.e., tolerances, limits, etc.).

Process variables (PVs) are the elements in the process domain that characterize the process that satisfies the specified DPs.

The decomposition is performed by zigzagging between the domains, starting from the “what” domain to the “how” domain.

The design process starts with identifying the customer needs (CNs). These are translated into functional requirements (FRs), which are matched with design parameters (DPs), and which in turn are converted into Process Variables (PVs) via experiments, drawings, purchased parts and manufacturing plans.

After establishing the top-level FRs and DPs, the decomposition proceeds until no further decomposition is needed and the design solution can be implemented (Park, 2014).

The mapping between the domains is represented by two design matrixes:

- product design matrix, which shows the relationships between FRs and DPs, and it can be summarized as {FR} = [D] {DP}
- process design matrix, which shows the relationships between DPs and PVs, and it can be summarized as {DP} = [B] {PV}

In the above formulas, $\{FR\}$ is the FR vector, $\{DP\}$ is the DP vector, and $[D]$ is the product design matrix, $\{PV\}$ is the PV vector in the process domain, and [B] is the process design matrix. For best results, it is recommended that the design matrix is a diagonal matrix (Qu *et al*., 2016).

The independence axiom is used during the decomposition to make sure that an acceptable design is achieved. Axiom 1 requires that the functions of the system be independent from each other, that is, each function can be achieved without affecting other functions.

Once FR and DP hierarchies are obtained, the second axiom, information axiom is used to find the best design solution. Among alternative designs which satisfy Axiom 1, the best design has the minimum information content.

After applying the axioms, the results show that the lower-level DPs violate the higher level design, the hierarchical structure that emerges from decomposition is known as the system architecture [SA]. A system architecture SA should be developed for every system to capture the performance requirements and components of the system in a logical, coherent, and comprehensive manner which is very useful in developing a reliability design (Shao *et al*., 2016).

### 2.4. Current state of research

Once the hierarchical structure of the system in terms of FRs, DPs, and PVs and corresponding design and process matrices is developed, it can be used to generate the flow diagram, which shows how design information must flow through the system design process.

The SA can capture the performance requirements and components of the system in a logical, coherent, and comprehensive manner, to facilitate communication between engineers, managers, and other stakeholders including the customer, and to provide good technical documentation of the design decisions made and the reasoning behind them.

Currently, there is no framework for applying Axiomatic Design in Project Management.

### 2.5. Research Methods

Managing projects of New Product Development presents many challenges, and while PMI provides sufficient guidelines on how to run a project, each company must adapt these recommendations to their own unique set of conditions. As Axiomatic Design is a very good method for solving product or process issues, it became apparent to find a way to use it for structuring projects. Currently there is no optimized model combining Axiomatic Design and Project Management.

In the current research, the goal was divided thematically so that the work was concentrated on finding whether AD was previously employed over the entire PM process, or for any subset of project or product lifecycle phases or for any subset of project activities. For a comprehensive result, Google Scholar, Sciencedirect.com, Researchgate.net and E-nformation.ro platforms were used.

### 2.6. Research Methods

In a query of “Axiomatic design literature review” several articles have been found and discussed below. Kulak *et al.*, 2010 introduced a novel classification method of articles and concluded that most articles are application-based studies mostly focusing on the application of the axiomatic design principles in Product Design, System Design, Decision Making, Software Design, and Manufacturing System Design.

Rauch *et al.*, 2016, identified that in Manufacturing system design, the AD was mainly used as a method for practical applications in Virtual, Cloud, Sustainable, Transport and Distributed Manufacturing, as well as Lean, Agile, Flexible, Automated and Cellular manufacturing systems, in addition to Lifecycle Management and Manufacturing Processes in general.

Marchesi *et al.*, 2013 investigates the applications of AD to architectural systems and finds that AD was used in Urban Planning, Building Design, Existing building improvements, Project management, and Furniture design for solving specific design problems. In the category of Project Management, the authors mentioned Eliasson and Psilander, 2000, Sohlenius (Sohlenius, 2000), and Sohlenius and Johansson, 2002.

Eliasson and Psilander, 2000 investigated the use of AD to improve customer satisfaction, process efficiency and therefore, a profit increase.

Sohlenius (Sohlenius, 2000) presents a decision-making framework for combining AD with Qualitative Methods in defining the customer requirements, especially according to aesthetic and social values in order to maximize profitability.

Sohlenius and Johansson, 2002 propose a framework that combines AD with the Theory of Flexibility and Robust Design, Theory of Inventive Problem Solving and Quality Function Deployment to improve the conceptual design phase of the housing development process, and to meet the customer’s requirements in an efficient way. Extensive attention is given to the market analysis in terms of demand, supply, and regulations to better identify and quantify constraints and FRs.

In a query of "Project management and axiomatic design" results are extremely limited. Weber et al., 2017 present an approach for the use of AD in agile project management in order to formulate and structure the work packages so that they can be processed independently.

Rauch *et al.*, 2015 shows the application of AD to the design of a lean product development process which can be used as templates. The functional requirement is to Improve Customer Value in Product Development through Lean Product Development Process (i.e. Design parameter).

The following queries, focused on finding studies applying AD to any of the Project Management Knowledge Areas, are discussed below.

Lobo *et al.*, 2000 proposes the use of AD to teach company's strategy to workers. The strategic objectives are used as functional requirements and all work is designed accordingly, linking performance measurement systems across all levels of the hierarchy to evaluate the solutions implemented to achieve the chosen strategy.

Engelhardt and Nordlund, 2000 describes the use of AD to create business strategic plans. The company goals are used as functional requirements, company strategies become the design parameters and activities are the process variables. AD can be used to optimize the implementation process, also known as action plan, by identifying tasks that can be performed independently.

Hintersteiner and Zimmerman, 2000 discuss the Axiomatic Design Capability Maturity Model developed to provide a road map and to track efforts for integration of AD to an engineering organization.

Gumus *et al.*, 2004a,b presents the use of AD to better the management requirements. A template for requirement description based on requirements attributes is developed to capture the requirements right. And to plan, communicate and track the system development activities throughout the lifecycle.

Braha (Braha, 2002) proposed a method linking AD to specifying and partition tasks in a team involved in the product design and development process. The model can be implemented within a decision support system and it can indicate areas for improvement.

Steward and Tate, 2000 explores the integration of AD into the process of project planning and task assignment for software development. This leads to early identification of dependencies and resources needed.

Vareilles *et al.*, 2012, discusses a model to support the project planning process controlling the system design project. It applies to local decoupling mechanisms between domains, but it cannot be generalized to a whole system.

Lee and Jeziorek, 2004, introduces a logical framework to cost engineering using AD. In this framework the functional domain (FRs), physical domain (DPs), cost domain (CUs), and a task/process-based model are linked providing traceability from requirements to cost information.

Suh (Suh, 1995) presents the use of AD's Independence Axiom to improve the quality of design by providing the bounds for statistical process control.

Khandekar and Chakraborty, 2016, presents a method based on fuzzy axiomatic design applied to personnel selection using a set of 18 evaluation criteria.

Arsenyan and Büyüközkan, 2009, uses AD to structure Collaborative Product Development environment to share risks and reduce time to market.

Mollajan *et al*., 2023 studied the use of AD to modularize the physical and the architecture for information flow in a contract.

Suh (Suh, 2006; Suh, 2009) uses AD and complexity theory to propose heuristic rules for collaboration and negotiation in the development of engineering systems by establishing basic principles easy to be adopted by anyone. The quality of the collaboration is given by the system as well as the process used.

Ilbahar *et al*., 2022, uses fuzzy information axiom to prioritize project alternatives once the risks have been identified.

Kannan *et al*., 2015, uses fuzzy AD to select the best green supplier for Singapore-based plastic manufacturing company by evaluating the requirements of both the manufacturer (design needs) and the supplier (functional needs). The method helps select the most appropriate supplier as well as its best alternative.

Kurniawan *et al*., 2004, presents a systematic approach to connect customers in the development process using AD by capturing their needs through a platform termed Design by Customer.

Table 3 summarizes the results presented above, linking AD to Project Management processes.

This study shows that AD is applicable to a multitude of processes utilized in all areas of Project Management. There are 49 processes identified by PMI, and not all of them have been addressed by researchers, so an expansion of AD theory on other processes would be beneficial to the industry. As Vareilles *et al*., 2012 observed, the method is better used in decoupled systems. An immediate benefit will be seen in the use of AD to scheduling tasks as well as improving communication and collaboration within the team, with the partners, or with the customers. As a result, integrating the requirements of the product as well as the requirements from all other areas contributing to the completion of the project will lead to better business plans, reduce risks, improve quality, improve budgeting, select better teams and partners, and reduce time to market.

**Table 3**
*Project Management Knowledge Area and authors*

| Authors | Project Management Knowledge Area | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integration | Scope | Schedule | Cost | Quality | Resources | Communications | Risk | Procurement | Stakeholder |
| Engelhardt and Nordlund, 2000 | x | | | | | | | | | |
| Hintersteiner and Zimmerman, 2000 | x | | | | | | | | | |
| Gumus and Ertas, 2004a, b | | x | | | | | | | | |
| Braha, 2002 | | | x | | | | | | | |
| Steward and Tate, 2000 | | | x | | | | | | | |
| Vareilles *et al.*, 2012 | | | x | | | | | | | |
| Lee and Jeziorek, 2004 | | | | x | | | | | | |
| Suh, 1995 | | | | | x | | | | | |
| Khandekar and Chakraborty 2016 | | | | | | x | | | | |
| Arsenyan and Büyüközkan 2009 | | | | | | | x | | | |
| Mollajan *et al.*, 2023 | | | | | | | x | | | |
| Suh, 2006 and 2009 | | | | | | | x | | | |
| Ilbahar *et al.*, 2022 | | | | | | | | x | | |
| Kannan *et al.*, 2015 | | | | | | | | | x | |
| Kurniawan *et al.,* 2004 | | | | | | | | | | x |

## 3. Conclusions

Project Management is a methodology typically employed to integrate a company's business processes in order to develop a new product, regardless of whether the product is tangible or intangible. In this study, the author researched papers that analyzed the application of Axiomatic Design to processes utilized in the Project Management of New Product Development. It was found that there is some development done in this direction and several processes from each knowledge area have been treated by several authors.

The author argues that the complexities occurring during the development of a new product could not be incorporated into one article and it is in the interest of commercial companies to develop a platform that links product requirements to companies processes in order to improve quality and profit.

Additional research is needed to study the application of Axiomatic Design to all the processes that have not been included in the current study.

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## APLICAREA PROIECTĂRII AXIOMATICE ÎN MANAGEMENTUL PROIECTELOR DE DEZVOLTARE PRODUS NOU – CERCETARE A LITERATURII

(Rezumat)

Articolul investighează aplicațiile metodei axiomatice de proiectare în cadrul managementului de proiect pentru dezvoltarea de noi produse. Lucrarea se concentrează mai mult pe procesele asociate managementului de proiect și mai puțin pe activitățile legate de proiectarea produselor. Rezultatele investigației relevă faptul că aplicarea proiectării axiomatice ar putea fi utilă și ar putea duce la îmbunătățirea șanselor de succes al proiectului și a rentabilității investiției. Se concluzionează că cerințele clientului ar putea fi utilizate pentru modelarea uniformă a majorității proceselor utilizate în managementul proiectelor, în funcție de organizarea internă a companiei și de complexitatea proiectului. Rezultatele sunt benefice managerilor de proiect pentru finalizarea cu succes a oricărui proiect în derulare.