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► **To cite this version:**

Hamidreza Pourzareï, Louis Rivest, Conrad Boton. Cross-Pollination as a Comparative Analysis Approach to Comparing BIM and PLM: A Literature Review. 17th IFIP International Conference on Product Lifecycle Management (PLM), Jul 2020, Rapperswil, Switzerland. pp.724-737, 10.1007/978-3-030-62807-9_57. hal-03753127

HAL Id: hal-03753127

<https://inria.hal.science/hal-03753127>

Submitted on 17 Aug 2022

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Cross-Pollination as a Comparative Analysis Approach to Comparing BIM and PLM: A Literature Review

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Abstract. Comparison is at the center of many research studies that leads to the interaction between different objects and mostly resulted in significant improvements. Especially, comparing business/technological approaches, such as building information modeling (BIM) and product lifecycle management (PLM), is an activity that is often difficult and complex, and requires particular methodological approaches. One of the biggest challenges through such a comparison is to identify the most effective methodological approach. Previous research studies have introduced cross-pollination as an interesting comparative analysis approach. However, it is important to mention that it remains a relatively untapped approach in the literature. This article provides a review of the cross-pollination variants and related terms and steps. Research findings of comparative analysis methods and approaches are evaluated to demonstrate the similarities and differences. This evaluation leads this research to represents the lessons learned of the existing methods and approaches.

Keywords: BIM, PLM, Comparison, Comparative Analysis, Cross-Pollination.

1 Introduction

Comparison is fundamental to human thought and ever present in world observation, which makes thinking without comparison unthinkable [1]. Many research studies focus on comparing two or more objects with different aims, such as benchmarking, interaction and inspiration. Furthermore, various research studies have focused on comparing objects in different domains, such as BIM and PLM ([2]–[10]), two business/technological approaches ([11] and [12]), two systems [11], two perspectives [12], and two business models [13]. The comparison can possibly bring the improvement of productivity between the intended objects. Accurate comparison is usually a difficult task, and it comes with different types of challenges, two of the most significant of which are how to compare objects and how compared objects can learn from and interact with each other.

A variety of methods and approaches have been proposed to address these two challenges, such as statistical and mathematical methods, and modeling techniques ([13]–[15]). However, these techniques are not sufficient for the comparison of two holistic

approaches involving multiple components and dimensions (e.g. BIM and PLM). One possible avenue for the comparison of such approaches is cross-pollination. While it has been mentioned a few times in the literature, it remains relatively uncommon and seems far from being clearly formalized as an effective comparison approach. This article presents the first steps of a more comprehensive research project that aims to compare BIM and PLM approaches, from the standpoint of the engineering change management. It reviews the dedicated literature in order to define cross-pollination as a comparison method, and to analyze how it has been used in different research studies.

This article is followed into five sections. Section 2 reviews the selected literature; we identify the cross-pollination and its different terms. Section 3 represents an investigation of how these methods and approaches have been used through different research studies, as well as what are the methods and steps for effective cross-pollination. In section 4, this article analyzes the various types of pollination (cross-pollination and its equivalent terms). The fifth section discusses the results. Finally, the last part wraps up the article with the conclusion and future works.

2 Terms and Variations of Cross-Pollination

This section aims at defining the cross-pollination as well as identifying its related terms and variants. Generally, when referring to the concept of cross-pollination or its different terms, we thought of a method or approach that can let two or more objects to interact and/or compare with each other. More precisely, several research studies have used cross-pollination to compare objects and find common and transferable characteristics for improvement. Interestingly, the term “cross-pollination” in the context of comparison is inspired by the pollination mechanism of plants [16], [17]. Pollination can be described as pollen transmission in the same plant or between plants from one flower to another [17]. There are two types of pollination mechanisms:

- *Self-pollination* – When the pollen from a flower pollinates the same flower or another flower on the same plant [18].
- *Cross-pollination* – When pollen grains are moved to a flower on another plant [18].

Although most research studies used the term “cross-pollination” for comparison, some others used different terms and variants, such as “cross-fertilization” and “bi-directional coordination and interaction.” While there are many different terms in use to refer to cross-pollination, the following four were selected from the literature because they were used in the context of comparative analysis:

- *Flower pollination* – This is the earliest of the terms used to define the pollination mechanism. Xin-She Yang [19] proposed a flower pollination algorithm that was inspired by the pollination mechanism used by plants [19]. The flower pollination algorithm is proposed for many design applications in engineering and industry.
- *Cross-pollination* – This is one of the terms most commonly used in research studies. It has been used in different research domains, such as software development [20],

optimization [21], comparative studies in education [22] and the comparison of BIM and PLM [2], [3], the oil & gas industry and space & satellite sector [23], partnerships in healthcare [24].

- *Cross-fertilization* – This term is commonly used when focusing on interaction. It is used when comparing objects and enables collaboration, such as in the case of the research of Piètre-Cambacédés and Bouissou [25], to identify potential common characteristics between safety and security engineering. It is also used for comparing building design and engineering design [26] as well as the construction industry and manufacturing [27].
- *Bi-directional coordination and interaction* – This is another term that is used when focusing on interaction, for example, in the research of Wiesner et al. [11]. The authors used this term for comparing service lifecycle management (SLM) and product lifecycle management (PLM) and finding potential for collaboration.

These terms and variants will be analyzed further in the next section by investigating how they were used in different domains.

3 Use of Cross-Pollination as a Comparative Analysis Approach

Now that cross-pollination and its equivalent terms and variants have been defined, this section goes on to investigate how these terms have been used in various research studies. Here is a sampling of the research studies:

- *Cross-pollination for BIM and PLM comparison* – Botton et al. [2], [3] compared BIM and PLM from a product structure (PS) standpoint and indicated that cross-pollination between BIM and PLM could benefit both the construction and shipbuilding industries in terms of knowledge transfer. The authors investigated further by conducting a practical study in the construction and shipbuilding industries to provide an in-depth understanding of these two industries. They aimed to identify equivalent notions in the construction and shipbuilding industries from a product structure standpoint, and mentioned “comparing BIM and PLM is a useful endeavor that could help improve both domains through cross-pollination” [2]. In addition, this comparison facilitated cross-pollination between the technological approaches of the two domains, so as to interact and benefit from the knowledge transferred between the two industries.

Flower pollination algorithm (FPA) – One of the initial research studies that used “cross-pollination” or more precisely “pollination” is that of Xin-She Yang [19]. Their research suggests that in many design applications for engineering and industry, under highly complex constraints, we will try to find the optimal solution to a given problem. Such unique optimization problems are often highly nonlinear, and finding the optimal solution is often a very difficult, if not impossible, task. Xin-She Yang [19] introduced a new algorithm, the FPA inspired by flowers’ pollination process. The algorithm was later developed and used by other researchers in different domains [28]. Kaur and Kumar [17] used the concept of cross-pollination and the

FPA for selecting the optimum number of base stations and optimizing site locations in wireless communication. Valenzuela et al. [18] used a fuzzy inference system to improve the FPA to solve complex optimization problems. Moreover, the work of Deepa and Rasi [29] used the FPA to resolve color image segmentation.

- *Cross-pollination between critical pedagogy and democratic education* – The research of Edwards [22] compares and contrasts the potential of connecting democratic education and critical pedagogy for cross-pollination. Three steps were proposed in this research to achieve cross-pollination: 1) investigate critical pedagogy and democratic education, 2) conduct a comparative analysis (of similarities and differences, using both theoretical and empirical studies), 3) identify the possibilities for cross-pollination.
- *Cross-pollination for software development* – The research of Hantos and Gisbert [20] aimed to introduce a framework for cross-pollination between software development and alternative disciplines. The research illustrated that cross-pollination can foster improvements in software development relatively inexpensively, providing subtle benefits in individual and group settings [20]. The proposed framework has three steps:
 - *Selection* – Select a case study from another discipline that offers potentially relevant problem solving or process improvement examples.
 - *Analysis* – Analyze the case study, record observations and debate the case study issues in their context. In the end, this part classified the results of observations into one of the three categories: people, process or technology.
 - *Mapping, evaluation and emulation* – This step systematically maps the collected solutions or process improvement ideas to practical solutions and improvement approaches in the target discipline and then devises methods to emulate and implement these techniques.

It is important to mention that the case study proposed compares observations as well as unique challenges in the construction and software domains based on the proposed categories—people, process, and technology [20]. In the end, they evaluated and rated the results to identify the potential for cross-pollination.

- *Cross-pollination for optimization* – Soni et al. [21] proposed a unified (algorithm) approach to enable the cross-pollination of ideas between established communities, which would help with the mapping of sequential decision-making problems (SDMP). The interesting point of this approach is that it required both theoretical and experimental research on algorithm performance.
- *Cross-pollination between the oil and gas industry and space and satellite sector* – Over the years, experts from both the upstream oil and gas industry and the space and satellite sector have noticed many striking similarities between the two domains, resulting in many direct media and industry press correlations [23]. Despite the fact that the two sectors have also intersected in academic literature, little sharing or cross-pollination has occurred in terms of asset maintenance. The research of Perons and Richards [23] argues that the oil and gas industry could significantly improve the maintenance of its assets by selectively applying some aspects of the maintenance strategies and philosophies used in space and satellite sector [23]. The

authors considered maintenance as the standpoint for their comparison to facilitate cross-pollination.

- *Cross-pollination for partnerships in healthcare* – Partnerships are a common approach to delivering healthcare [24]. Despite evidence from various settings of the challenges of putting partnerships into practice, there has been little cross-pollination between literature from different fields [24]. These problems led Aveling and Martin [24] to evaluate partnerships through a comparative analysis of two case studies of multi-level partnerships in different contexts in the UK National Health Service and an internationally funded health program in Cambodia. Two points were of particular interest in this research: first, using partnering as the comparison standpoint facilitated both comparison as well as cross-pollination, and second, the authors analyzed both theoretical and empirical studies.
- *Cross-fertilization between building design and engineering design* – It is important to use design models to promote information exchange between engineering designers in both the construction industry and manufacturing [26]. It could be assumed that the use of design models varies between the two fields and that the models used in building design are more suitable for integrating discipline-specific perspectives than those used in engineering design. Based on these assumptions, the objective of the study of Eisenbart and Blessing [26] was to investigate the reasons for using different design models for cross-fertilization. Building design and engineering design were comparatively analyzed based on three categories of comparison: 1) comparison of the development process, 2) comparison of communication within the development process, and 3) comparison of the use of design models within the development process.
- *Cross-fertilization between safety and security engineering* – Safety and security developed over many years as two distinct disciplines, led by discrete communities to develop their own tools and methodologies [25]. The research of Piètre-Cambacèdes and Bouissou [25] aimed to highlight the potential for cross-fertilization between safety and security engineering by evaluating related initiatives and outcomes in scientific literature and industry practices. The authors sought to identify commonalities and distinguishing features of safety and security through different perspectives to facilitate their comparison. Cross-fertilization was well implemented in this research by organizing how safety and security interact with each other. The authors classified the characteristics of these objects that interact into three groups:
 - Existing characteristics for cross-fertilization, with interactions divided into two sub-classes: 1) from safety to security, and 2) from security to safety.
 - Potential characteristics for cross-fertilization, ones that have the potential to interact, divided into two sub-classes: 1) from safety to security, and 2) from security to safety.
 - Characteristics for safety and security integrated tools – the authors thought that in some cases, combining the characteristics of both domains could be more efficient [25].
- *Cross-fertilization between the construction industry and manufacturing* – The research of Sanvido and Medeiros [27] used the term “cross-fertilization” to investigate ways and approaches to develop an integrated process model for construction

and manufacturing. The comparison in their research was followed by two perspectives—first, comparing the process modeling approaches used in both construction and manufacturing, and second, comparing the integrated process model in construction and manufacturing. From their investigation, they proposed potential candidates for cross-fertilization.

- *Bi-directional coordination and interaction* – The research of Wiesner et al. [11] used this term for the interaction between service lifecycle management (SLM) and product lifecycle management (PLM). They aimed to “combine PLM and SLM approaches to support the lifecycle of integrated product-service systems” [11]. According to their research, the collaboration consists of four cooperative processes in the phases in which PLM and SLM are not yet fully integrated: coordination, the exchange of information, negotiation and conflict resolution [11].

Table 1 summarizes the terms and variants as well as their intended domain.

Table 1. Terms and variants of pollination and their intended domain

<i>Author(s)</i>	<i>Term Used</i>	<i>Intended Domain</i>
Boton et al. [2]	Cross-pollination	Comparing BIM and PLM
Xin-She Yang [19]	Flower pollination algorithm	Solving optimization problems
Kaur and Kumar [17]	Cross-pollination (+ flower pollination algorithm)	Optimizing site locations in wireless communication
Valenzuela et al. [18]	Flower pollination algorithm	Solving optimization problems, with a fuzzy inference system
Deepa and Rasi [29]	Flower pollination algorithm	Resolving color image segmentation
Edwards [22]	Cross-pollination	Comparing educational systems
Hantos and Gisbert [20]	Cross-pollination	Comparing different software development disciplines
Soni et al. [21]	Cross-pollination	Comparing algorithms in decision-making problems
Perrons and Richards [23]	Cross-pollination	Comparing the oil and gas industry and space and satellite sector
Aveling and Martin [24]	Cross-pollination	Comparing partnerships in healthcare
Eisenbart and Blessing [26]	Cross-fertilization	Comparing building design and engineering design
Piètre-Cambacédés and Bouissou [25]	Cross-fertilization	Comparing safety and security engineering
Sanvido and Medeiros [27]	Cross-fertilization	Comparing the construction industry and manufacturing
Wiesner et al. [11]	Bi-directional coordination and interaction	Comparing SLM and PLM

The following section evaluates the aforementioned terms and variants and their intended domain to extract the similarities and differences between them.

4 Analysis of Various Types of Pollination

This part aims to analyze the results and identify the similarities and differences between different types of pollination (cross-pollination and its equivalent terms). Interestingly, most of the research studies used the same three-phase structure for comparison: compared concepts and defined terms, comparative analysis and pollination. In some cases, the order varies or one step is skipped (but still considered indirectly). The structure is summarized in Table 2.

Table 2. Comparative analysis structure for different types of pollination

<i>Author(s)</i>	<i>Compared concepts and defined terms</i>	<i>Comparative analysis</i>	<i>Pollination</i>
Boton et al. [2]	PLM, BIM, BOM, product structure, discrete manufacturing.	<ul style="list-style-type: none"> Comparing product Beginning-of-life (BOL) in shipbuilding and construction. Analyzing Bill of Materials (BOM) and Product Structure (PS) concepts in shipbuilding and identifying equivalent notions in construction. Comparing PLM in shipbuilding and BIM in construction from different perspectives. 	<ul style="list-style-type: none"> Demonstrate which equivalent elements distinguish BIM in construction and PLM in shipbuilding.
Wiesner et al. [11]	PLM; PDM; SLM; various phases of the product lifecycle (BOL, Middle-of-life (MOL) and End-of-life (EOL)) and service lifecycle (service creation, service engineering and service operations).	<ul style="list-style-type: none"> Identifying the occurring interaction pattern between PLM and SLM through four case scenarios: 1) SLM follows PLM, 2) PLM follows SLM, 3) SLM is aligned with PLM, 4) SLM is integrated with PLM. 	<ul style="list-style-type: none"> Determine the patterns that exist in terms of interaction between PLM and SLM. Identify areas in which PLM and SLM are not completely integrated (coordination, the exchange of information, negotiation and conflict resolution).
Piètre-Cambacédès and Bouissou [25]	Safety, security, related concepts such as risk.	<ul style="list-style-type: none"> Comparing the similarities and differences between safety and security from different perspectives, such as similarities in design and operation principles, and differences in the rating of consequences. Comparing the existence of the interactions between safety and security. 	<ul style="list-style-type: none"> Propose characteristics for cross-fertilization between safety and security.
Perrons and Richards [23]	---	<ul style="list-style-type: none"> Identifying best practices from space and satellite industry. Comparing two domains from the standpoint of maintenance. 	<ul style="list-style-type: none"> Recommend four research questions to accelerate the rate of learning and sharing (pollination) between two industries.

Aveling and Martin [24]	Partnership in healthcare.	<ul style="list-style-type: none"> • Comparing instrumental and transformative partnerships. • Comparing partnerships from different perspectives (i.e., partnership in high- and low-income countries). • Comparing partnerships in two practical studies. 	<ul style="list-style-type: none"> • Identify opportunities for improvement in partnerships.
Eisenbart and Blessing [26]	Design models in product development and building design.	<ul style="list-style-type: none"> • Comparing the design models used in product development and building design. • Comparing the development process used in building design and engineering design. • Comparing communication in both industries. 	<ul style="list-style-type: none"> • Identify opportunities for cross-pollination between the design models used in building and product development.
Edwards [22]	Critical pedagogy and democratic education.	<ul style="list-style-type: none"> • Comparing critical pedagogy and democratic education from different perspectives (i.e., classroom, government). 	<ul style="list-style-type: none"> • Propose opportunities for cross-pollination between critical pedagogy and democratic education.
Hantos and Gisbert [20]	Cross-pollination.	<ul style="list-style-type: none"> • Comparing two practical studies in the construction and software domains using the proposed framework. 	<ul style="list-style-type: none"> • Propose a framework for cross-pollination that has three steps: 1) selection, 2) analysis, and 3) mapping, evaluation and emulation. • Address three categories (people, process and technology) in the analysis step.

On one hand, some research studies used a single standpoint, such as *maintenance* [23], *product structure* [2] and *partnership* [24], for their comparative analysis. On the other hand, multiple standpoints are used to identify similarities and differences, for instance, “similarities in design and operation principles” or “differences in the rating of consequences” [23].

In the literature, the researchers classified two types of pollination characteristics [25]: 1) characteristics of the first object that are mapped and used on the second object to convey its benefits, and 2) potential characteristics that can be transferred to the other object or combined to create the new characteristics that can be applied to both objects. These types of pollination characteristics are mapped and explained briefly in the following section.

5 Discussion

After reviewing the selected literature on comparative analysis methods and approaches, the next step is to identify the lessons learned that can be used to compare BIM and PLM, considered here as holistic objects involving multiple components.

The first issue is to consider the comparative analysis structure used in most types of pollination and it has three phases: compared concepts and defined terms, comparative analysis and pollination. This structure was presented briefly in Table 2. The structure can help to organize the comparison. On the other hand, several standpoints have been used to organize and facilitate comparison, for instance, maintenance for comparing space and satellite sector with oil and gas industry [23], product structure for comparing BIM and PLM [2], and partnership for comparing two healthcare systems [24]. Therefore, using a standpoint can be considered as the other lesson learned.

Three pollination patterns were extracted from the literature review and definitions are proposed here after: self-pollination, cross-pollination (transposition) and cross-pollination (combination).

- *Self-pollination* – This type of pollination aims to create or improve the components that are the result of self-pollinating. Self-pollinating means self-improvement or self-learning that one holistic object can learn from itself.
- *Cross-pollination (transposition)* – This type of pollination aims to create or improve the components of one holistic object by transposing and adapting some components from another holistic object in order to extend the capabilities of this holistic object.
- *Cross-pollination (combination)* – This type of pollination aims to create a new holistic object by combining components from other holistic objects, in order to build on the strengths and mitigate the weaknesses of the parent holistic objects.

Figure 1 illustrates three patterns of pollination: self-pollination, cross-pollination (transposition), and cross-pollination (combination), which represents the holistic objects and their components before and after pollinating.

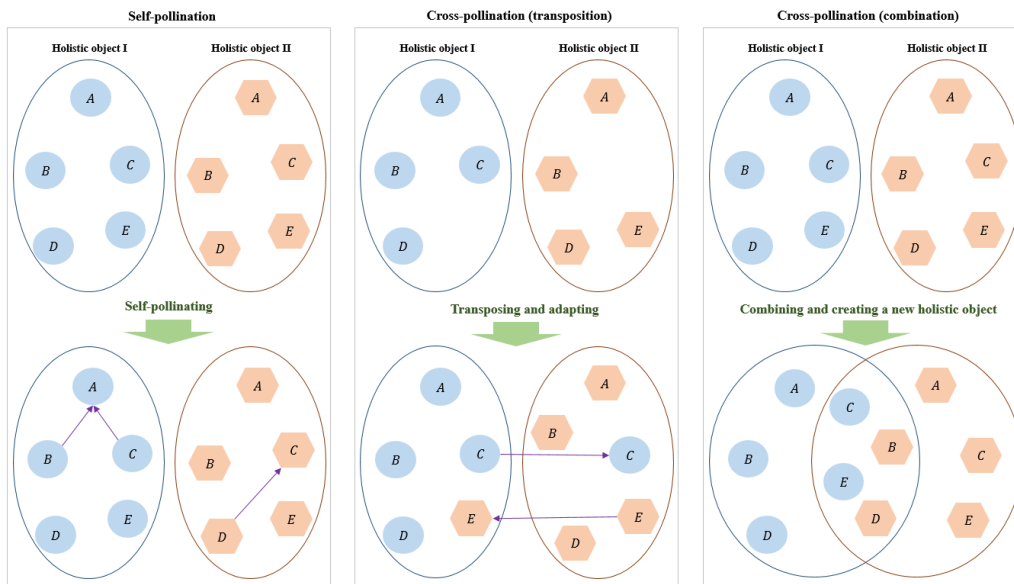


Fig. 1. Three patterns of pollination

Digital Twin in both manufacturing and construction is an example of self-pollination that can result in different types of improvements such as optimizing the processes and virtual control. Since both the physical and the virtual component that are being compared belong to the same universe (be it BIM or PLM), it is considered as self-pollination.

A common idea for the BIM and PLM comparison is that the mature functionalities of PLM could be tailored to the specific context of the construction and infrastructure industry to effectively manipulate complex BIM models (transposition) [6]. In addition, several research studies ([2], and [30]) suggest that BIM and PLM cross-pollination would be more beneficial and provide an opportunity to improve efficiency and productivity in both BIM- and PLM-supported industry (transposition).

Some research work studied cross-pollination in BIM and PLM either by mentioning the term cross-pollination or not, such as the research of Aram and East-man [31] that discussed “the potential benefits of adopting the PLM solution in the AEC industry” (transposition) as well as proposing a conceptual model for integrating PLM solutions with BIM servers (combination). Jupp and Singh [32] and Jupp [33] investigate the opportunities that PLM can address in BIM (transposition). The work by Biccari et al. [9] and Botton et al. [2] also studied these types of improvement between BIM and PLM by considering, respectively, configuration view and product structure as a standpoint (transposition and combination).

Hence, various investigations between BIM and PLM can be considered as belonging to the different types of pollination such as self-pollination—do the improvement by self-learning, cross-pollination (transposition)—transposing and adapting components from another holistic object, and cross-pollination (combination)—create a new holistic object by combining components from other holistic objects.

As mentioned, the cross-pollination (combination) can create a new holistic object by integrating or combining the components that can be used in different domains. For instance, in the research of Cheutet et al. [7], the characteristics and functionalities of BIM and PLM are integrating together to be used in the nuclear facility decommissioning.

6 Conclusion and Future Works

The concept of cross-pollination in research refers to the influence of interaction between two objects that can lead to a gain by comparative analysis. This article aimed to review the dedicated literature about cross-pollination as a comparison method and to analyze how it has been used in different research studies.

This investigation resulted in three achievements. First, the comparative analysis structure used in most types of pollination has three phases: compared concepts and defined terms, comparative analysis, and pollination. Second, comparing complex objects could be better performed according to a specific standpoint. Third, three pollination patterns were extracted from the literature review and definitions are proposed here after: self-pollination—do the improvement by self-learning, cross-pollination (transposition)—transposing and adapting components from another holistic object, and

cross-pollination (combination)—create a new holistic object by combining components from other holistic objects.

Globally, this preliminary investigation reveals that literature uses the concept of cross-pollination as an approach to compare two holistic objects. However, cross-pollination does not appear as a carefully defined mechanism for comparison. For instance, some research studies proposed 2, 3, or 4 phases for doing cross-pollination, and do not propose an accurate comparison framework. Hence, authors will decide either using cross-pollination, by proposing a more accurate version of cross-pollination, or investigating more for other approaches.

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