A Metamodeling Approach for Planning Critical IoT Systems

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Abstract. *This paper presents a metamodeling approach to address the lack of methodological support in canvas model development, focusing on planning critical IoT systems. We introduce MM4Canvas - a metamodel that provides a solid foundation for developing structured and standardized canvas models, allowing for consistent reuse and extension across diverse project types. A proof of concept was conducted by instantiating a general-purpose canvas model based on MM4Canvas for project planning, aiming to establish a connection between this activity and the Requirements Engineering process. We extended this model to incorporate safety and security requirements for critical IoT systems. Our contribution demonstrates the metamodel's capacity to support standardization, reuse, and extensibility in canvas-based project planning.*

keyworks: Metamodel, Project, Planning, Agile, Canvas, Safety, Security, IoT, Systems, Requirements

1. Introduction

The purpose of the *project planning* process is to create and coordinate effective plans that outline project objectives, assumptions, constraints, and the scope [10]. Project planning is not inherently part of the Requirements Engineering (RE) process but is closely intertwined [20]. Both necessitate determining and analyzing the project scope. Therefore, we begin with the premise that it is beneficial to undertake these activities jointly at the beginning of a project. The connection between planning and RE becomes particularly apparent in agile software development contexts, where continuous project planning often aligns with core RE practices [2].

Agile approaches discard long periods of preliminary analysis but recognize the importance of defining project directions and understanding your requirements [3]. In this context, a challenge often faced in practice is finding the balance between agility and efficiency, focusing on artifacts that add value to the project [9, 19]. Project planning and RE share this concern.

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Planning is a critical step for the success of a project [32], being the object of interest of several studies and with different perspectives, ranging from the proposition of models and tools [1] up to the level of stakeholder involvement [7]. However, many organizations face difficulties in incorporating project planning practices, making it a challenge, especially for those dealing with complex projects and needing to involve diverse stakeholders [25].

Aiming to minimize these difficulties, improve communication and collaboration, and make project planning more practical and understandable compared to traditional approaches, Tezel et al. [28] highlight the growth of visual tools for different contexts and domains of application. This movement originates in the *Lean* approach, which aims to add value to the customer, improve processes, and promote efficiency and continuous improvement [12].

Given the overlap between project planning and early RE activities, the goal should not be to produce a highly detailed plan or a comprehensive requirements specification, as these could quickly become outdated. Instead, the focus should be on creating artifacts that guide the project in the right direction and serve as inputs for subsequent stages. In this context, the canvas approach has proven effective in defining scope and capturing essential project information, especially when collaboration among stakeholders is key, enhancing the clarity, analysis, and communication of ideas visually and effectively.

Currently, the use of canvas is widespread, serving diverse needs and applications in various fields. However, after conducting an ad-hoc study on the different types of canvas, encompassing a series of primary studies, e.g. [3, 26, 27] and a systematic review [29], we highlight the lack of methodological support regarding the construction of these artifacts, which implies problems, such as (i) lack of standardization; (ii) inconsistencies between models within a same domain; (iii) poor understanding of the canvas elements; (iv) difficulties in the reuse or extension of reference models; (v) misuse of general-purpose models for specific application domains; and (vi) poor effectiveness of the models due to one or more preceding cases.

In response to these challenges, this work presents a metamodeling approach for canvas development and methodological support, called *MM4Canvas*. This metamodel goal is to provide a solid foundation for modeling, analyzing, constructing, and maintaining canvas models, promoting consistent standardization, reuse, and specialization in different application domains. The metamodel enables the creation of canvas models for multiple purposes, including projects (the focus of this study), business, and others. As a proof of concept, *MM4Canvas* was applied to instantiate a reference project model canvas that supports project planning and initial RE activities. Furthermore, we reuse and extend this model to create a more specific canvas for planning and supporting the RE process of critical IoT systems, addressing safety and security requirements (SSR).

The structure of this paper is organized as follows: Section 2 presents background on the use of canvas, reference models, and metamodeling approach; Section 3 discusses related works; Section 4 proposes and details the *MM4Canvas* metamodel; Section 5 presents the proof of concept, with by instantiating of two canvas models from *MM4Canvas*; Section 6 discusses the results and contributions; and Section 7 brings our concluding remarks and future work.

2. Background

In this section, we present the fundamental concepts underlying our proposal, starting with an overview of the canvas approach and then discussing the use of metamodeling to propose a canvas model.

2.1. The Canvas Approach and Reference Models

A canvas is an artifact for prototyping a mental and visual model applicable to analyzing projects, businesses, or other purposes. As a strategic planning tool, its primary goal is to address fundamental questions related to the object of analysis. Each fundamental question encompasses components – elements that encapsulate and detail essential information according to the type of canvas – forming an interconnected structure to describe the intended subject. Canvas uses logic to build a visual map, helping to organize and define ideas, and must be accessible, viewable, and collaboratively adjustable as required.

As presented, the canvas approach is becoming more prevalent across various purposes and application domains. Analyzing this scenario, Osterwalder and Pigneur [22] are pioneers in adopting a canvas to describe, through a simplified model, the logic of creation, delivery, and value capture for a given business. The *Business Model Canvas* (BMC) comprises nine key components (Table 1) and has wide acceptance in the business planning area. It established the basis for various canvas types developed with the same principles and has been widely adopted as a reference model.

Table 1. Fundamental questions and components: BMC and PMC.

Questions	Canvas Type	
	BMC (business-oriented)	PMC (project-oriented)
Why	–	Justifications, Objectives, Benefits
What	Value Propositions	Product, Requirements
Who	Customer Relationships, Customer Segments, Channels	Stakeholders, Team
How	Key Partners, Key Activities, Key Resources	Assumptions, Delivery Groups, Constraints
When	–	Timeline
How much	Cost Structure, Revenue Streams	Risks, Costs

Exploring a more comprehensible and efficient project planning model, Finocchio [4] introduced the *Project Model Canvas* (PMC). While BMC focuses on conceiving new businesses, the PMC offers a novel approach to agile and efficient project planning, incorporating 13 key components tailored for this purpose (Table 1), grounded in project management concepts, with a logical sequence for fill and validation. Furthermore, BMC and PMC group components into fundamental questions presenting different perspectives on the analysis object. These questions derive from the idea of an action plan (5W2H), a set of questions used to compose strategic plans quickly and efficiently [13]. Table 1 compares BMC and PMC, showcasing the fundamental questions used by each canvas type and the components integrated into each question.

Starting from the analysis of the structure of the BMC and the PMC, consolidated canvas models for different purposes (businesses and projects, respectively), we can observe their constructions based on common elements. Both models have components that aim to support the extraction of specific information about the purpose of the analysis performed and are organized into blocks structured clearly and concisely. These components, in turn, in both models are grouped into fundamental issues. Similar behavior was observed in several other canvas models, whether inspired by these two reference models or not.

2.2. Metamodeling in Software Engineering

Metamodeling offers a formal and structured foundation for constructing and managing artifacts throughout a project's lifecycle in software engineering. It helps define rules, patterns, and structures that guide the creation and organization of artifacts, bringing consistency and quality to the process [6]. The metamodeling approach can help in the development of artifacts in several ways:

- *Definition of Common Structures*: Metamodeling establishes a common vocabulary and structure for artifacts, such as models, diagrams, requirements documents, and design specifications. With this, it is possible to create artifacts that follow a specific standard, facilitating understanding and integration among different teams and stakeholders.
- *Reusable Models*: Through a metamodel, it is possible to create artifacts that can be reused in different projects, saving time and effort in development.
- *Domain-Specific Extension*: In a metamodeling approach, it's possible to create domain-specific artifacts incorporating properties and requirements into the metamodel-supported instances.
- *Artifact Customization*: Metamodeling allows artifacts to be adjusted and customized according to the specific needs of the project or organization, promoting greater adherence to business and technological requirements.
- *Ease of Updating*: Using a well-defined metamodel simplifies artifact maintenance, as the artifacts are structured to adapt to changes and evolution in the system or project.

By providing a high-level structure, metamodeling helps to control and standardize the development and evolution of artifacts, promoting quality, consistency, and ease of maintenance. After examining multiple canvas models, we identified essential and common elements and an opportunity to introduce a metamodel-based canvas abstraction (see Section 4) aiming to provide methodological support for instantiating, reusing, and extending various types of canvas models to meet the specific needs of organizations and project teams.

3. Related Work

We conducted a literature review to identify works utilizing the metamodeling approach for planning activities, particularly those implementing canvas-based artifacts. The goal was to investigate how the canvas approach could reduce the complexity of planning while ensuring effective results.

The study of Meertens et al. [17] proposes an ontology-based metamodel, using a detailed view of the BMC elements to represent a formal basis for business modeling. The objective is to map the BMC into an open standard modeling language for specifying architectural descriptions and their motivation, ranging from business objectives to technological infrastructure.

Husen et al [8] proposes a metamodeling approach that integrates canvas-based analysis with traditional analysis techniques for machine learning (ML). A metamodel defines the relationships between the elements of the different models used in the development of the proposal. This metamodel merges components with the same concept (e.g., “value proposition”) into a single component and addresses the safety requirement.

Also working on metamodeling in the business context, Gottschalk et al. [5] propose an approach that uses the functions of a domain expert, a method engineer, and a business developer, together with a repository of method fragments to develop models and another with artifacts to support development.

In summary, the literature presents a series of works that use metamodeling to explore, in different ways, the business-oriented BMC-based approaches. When we analyzed the project-oriented vision, for example, using PMC, despite identifying a series of works that adopt this canvas model, no metamodel proposal or other type of abstraction supports its use for the terminal model’s instantiation.

Furthermore, the abstraction models found to refer to domain models (business, ML, etc.), and even though they have an appropriate level of abstraction for these purposes, they are specialized and do not allow the instantiation of canvas models for other purposes and application domains, such as projects in general. In the meantime, we observed the opportunity to propose a generic metamodel for a canvas that offers the necessary methodological support and allows the instantiation, reuse, and extension of models for any purpose, e.g., critical IoT systems projects, as presented in the proof of concept of this work.

4. *MM4Canvas*: a Metamodel for Canvas

This section presents the methodological path and development details of metamodel *MM4Canvas*.

4.1. Methodological path

We adopt Design Science Research (DSR) as the methodological approach due to its problem-solving nature and the systematic creation of artifacts. In this research, we apply the DSR-Model [23], which has three pillars:

- the **problem in context**, reasoned on the state of art: lack of methodological support in canvas model development.
- **behavioral conjectures**, based on a theoretical framework: a metamodeling approach improves canvas development, establishes standardization, and supports reuse and extension of models.
- the **proposed artifact**, based on the state of the practice, whose conception-driven by conjectures and addresses the problem: a canvas metamodel.

From the DSR-Model application, we identified the opportunity to propose a metamodel for canvas methodological support.

Analyzing different types of canvas on the state of practice [22, 4, 3], we identified the essential elements present in all canvas models (e.g., fundamental questions, components, and posts) and the relationships between them (e.g., inheritance, composition, association). By modeling these elements and specifying their relationships, we propose in this article a metamodel that allows their instantiation in general-purpose or application domain models to address different needs.

Another important characteristic for defining the metamodel was the canvas models categorization into (i) general-purpose canvas and (ii) application domain canvas. General-purpose models encompass components generic enough to avoid restricting the canvas to a single application domain. Still, designers create these models with a well-defined orientation to meet your purposes, such as projects (PMC) or business (BMC). Application domain models, such as MVP Canvas [3], IoT Canvas [26], and ML Project Canvas [27], are either based on general-purpose models or extensions of them, developed to cater to a particular application domain with specific characteristics.

The proposed metamodel, named *MM4Canvas*, adopts the MetaObjectFacility (MOF) metamodeling architecture [21], where the elements of the lower layers are instances of those in the immediately higher layers, as shown in Figure 1.

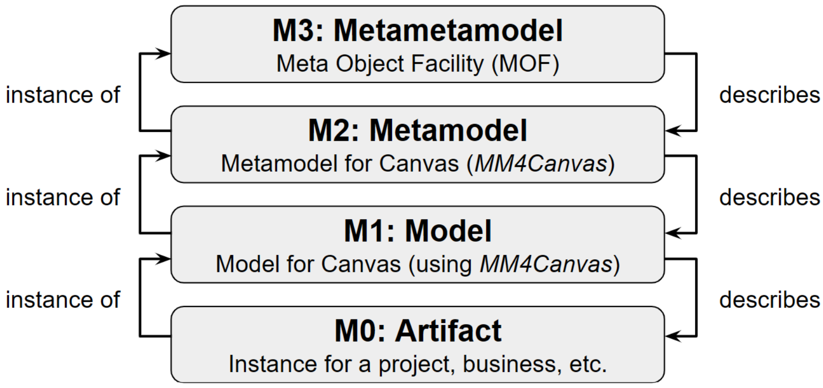

Figure 1. Integration between MOF and *MM4Canvas*.

The proposed metamodel (M2 layer) is an instance of the MOF (M3) and describes the possible terminal models, which are the different types of model canvas (M1) that can be instantiated. These canvas models are templates for canvas instances (M0) for projects, businesses, or other purposes, instantiated from the model canvas (M1).

4.2. *MM4Canvas*: elements and definitions

A general canvas abstraction was established from a set of essential elements, which we consider as pillars for the definition of *MM4Canvas* metamodel.

- **Canvas** (metaclass *Canvas*): represents the principal artifact that will be composed of the other elements. Its attributes describe essential about the instantiated model.
- **Fundamental questions** (metaclass *FundamentalQuestion*): these are high-level questions inspired by the idea of an action plan (5W2H) that articulate essential aspects of the project. They offer a perspective on the project by addressing key questions such as “what” needs to be done, “who” will do it, etc.
- **Components** (metaclass *Component*): elements that indicate a essential information or a specific need for a project, business, etc. Can be specialized in:
  - **General-purpose components** (metaclass *GeneralPurposeComponent*): in the case of a project-oriented canvas, for example, whose reference

model we adopted is the PMC, the general-purpose components are based on classic project management concepts (according to Table 1). These components are grouped into fundamental questions according to the type of information they describe about the project.

  – **Domain-specific components** (metaclass *DomainSpecificComponent*): these are components added as extensions to reference models (PMC or BMC) or that modify general-purpose components to expand the description capacity of a canvas model for projects with specific needs or requirements. Must be associated with a given domain (metaclass *Domain*).

- **Posts** (metaclass *Post*): short sentences that detail each component, describing essential information to a project, business, etc.
- **Relationships** (metaclass *Relationship*): components can be linked by relationships, defining relevant associations according to the needs of a canvas model. Every relationship between components (metaclass *CompRelationship*) starts "from" one component and goes "to" at least one other.

Figure 2 presents the proposed canvas metamodel *MM4Canvas*. As it is based on essential elements of canvas construction, and not on elements or relationships from a specific domain, the *MM4Canvas* metamodel, M2 level, is a reference for the construction of canvas models catering to different purposes (projects, business, etc.) and application domains, instantiated at the M1 level. A model, at the M1 level, comprises a set of fundamental questions defined and instantiated based on each type of model canvas intended. Each fundamental question consists of a components set, which can be general-purpose or domain-specific and have relationships. Each instantiated component will detailed in one or more posts, providing your descriptions at the M0 level.

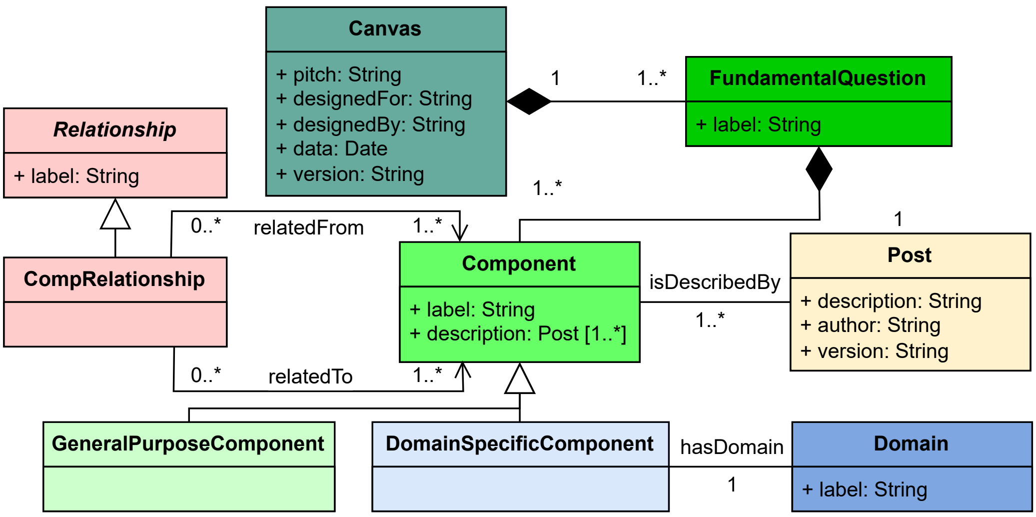

Figure 2. *MM4Canvas*: metamodel (M2) for creating canvas models.

5. Proof of Concept

To validate the proposed metamodel, we developed two models (M1) based on *MM4Canvas*: i) an instance for the widely-used general-purpose Project Model Canvas

(PMC), discussed in Section 2, and ii) a PMC-based extension tailored for critical IoT systems projects with safety and security requirements (SSR), called *SafeSecIoT Canvas*.

The project domain was chosen for this proof of concept due to its initial motivation for using a canvas model to support project planning and early RE activities. Through the studies aimed at proposing a canvas model, gaps were identified in the methodological support for canvas construction, which was addressed with the introduction of the *MM4Canvas* metamodel.

The specific application domain of critical IoT systems projects is motivated by the development of studies aimed at aligning safety and security requirements [16, 24, 30, 31]. These systems depend on specific requirements analysis techniques that can benefit from the initial gathering of information from the project through a canvas model properly built for this domain.

To accomplish this, we work initially with the fundamental questions, components, and relationships derived from the PMC methodology proposed by [4]. Then, we reuse and extend the established PMC model by incorporating specific components to meet the SSR domain needs [31].

5.1. Project Model Canvas (PMC): instantiating the metamodel

In the *MM4Canvas*-based PMC model (M1), presented in Figure 3, the fundamental questions and its components (general-purpose components, in this case) are instantiated by the proposed metamodel and in the PMC methodology [4] (see Section 3). We also map the existing relationships between these components, defining your connections. This model will guide the process of answering the project's fundamental questions and validating the information raised (M0).

The first part of the model comprises the "why" of the project, where the justifications (problems to be attacked and resolved), objectives, and benefits are intrinsically related. Justifications should directly correlate with benefits, resolving identified issues. Objectives must act as a bridge between the before/after scenario of the project, effectively addressing described issues and guiding the project towards the envisioned benefits.

Having defined the "why" of the project, we move on to the "what" must be described about him and a set of essential requirements. These requirements are motivated by the problems presented in the justification and must refer directly to the product. Furthermore, other canvas components can provide context and motivation for defining these requirements, which can defined throughout the entire canvas completion process.

The components corresponding to the fundamental questions "who", "how", and "when&how much" (addressed collectively in the PMC) are intricately interconnected, as illustrated in Figure 3. Ensuring that the information collected by each component aligns with the defined relationships is vital for validating the accuracy of an instance of this canvas. Project stakeholders must act as the "owners" of the requirements and provide assumptions for the project. The team is accountable for the delivery groups and is associated with restrictions linked to these. Project risks originate from assumptions and can threaten deliveries, requiring organization on a timeline and guiding project costs.

Utilizing the *MM4Canvas* metamodel to map fundamental issues, components, and relationships inherent to the PMC methodology enhances the effectiveness of the resulting model canvas. Firstly, it can be employed as a visual tool for project planning and gathering initial requirements by project teams and stakeholders. Moreover, it supports the validation of the artifact generated. Finally, as an instance of the *MM4Canvas*, this PMC model can be reused and expanded for diverse project finalities within specific application domains, as elaborated next.

5.2. *SafeSecIoT Canvas* model: reusing and extending the PMC model to support critical IoT systems project planning

Organizations typically address non-functional requirements (NFR) reactively, considering them only after designing and implementing the system [18]. This practice has the potential to generate problems and introduce defects that can significantly impact the project, resulting in higher costs for their correction [11]. Thus, developing a safety and security-dependent software system must address these concerns from the RE phase rather than treating it solely as a late-stage aspect of the development process.

In this context, after verifying the potential of a PMC for project planning and requirements elicitation (general-purpose canvas), we propose an extension of this *MM4Canvas*-based model aiming to reduce the complexity of the process of analyzing SSR for critical IoT systems from the inclusion of components to extract specific characteristics of this domain (application domain canvas). The analysis method presented by Veiga et al. [31] depends on surveying the scope of the system and specific characteristics related to the analyzed critical IoT system and safety and security concerns. For this, we instantiated an extension of the PMC called *SafeSecIoT Canvas*.

To build the*SafeSecIoT Canvas*, the general-purpose components of the PMC were reused, and IoT and SSR domain-specific components were incorporated, to meet the specific demands of these types of projects, extending and specifying the PMC scope. The IoT domain-specific components defined for *SafeSecIoT Canvas* based on consolidated studies:

- *Components*: refer to the hardware and software elements that comprise the system. Hardware includes sensors, actuators, or any object (thing) with identifying, sensing, or acting behaviors and processing capabilities that can communicate and cooperate to achieve a goal. The software includes algorithms for controlling and orchestrating IoT systems, user interfaces, and other components.
- *Connectivity*: is the way by which *things* can connect to materialize the IoT paradigm. That is not limited to the internet covering other media, such as Intranet, Bluetooth, and others, that can connect components.
- *Actions*: these are relevant interactions performed by the IoT system according to the application context, linked or not to the actuators, and can result in data.
- *Data*: any information from various sources and formats, often integrated into databases to support applications.

Regarding safety and security concerns, the following building blocks were defined:

- *Assets*: can be anything of value to the system that must be protected from accidental or malicious loss, including people, resources, environment, or services.
- *Losses*: are significant damages or negative impacts associated with an asset, unacceptable to stakeholders, caused by an accident or attack.

- *Risks*: are potential causes of accidents or attacks, of intentional or unintentional origin, linked to the safety or security of an asset.

Figure 4 introduces the *SafeSecIoT Canvas*, which reuses the general-purpose components of the PMC model and includes the IoT and SSR domain-specific components.

Reinforced the stated, the purpose of a PMC is to offer guidance for the project planning, streamlining the definition of essential information, the early RE stages, and fostering necessary communication among stakeholders. In this way, the *SafeSecIoT Canvas* model has all the characteristics of a PMC, allowing the planning of a project with specific characteristics and requirements in the application domain of critical IoT systems with SSR.

5.3. *SafeSecIoT Canvas* artifact: instantiating the model

At the M0 level, a model is instantiated as an artifact that stakeholders will use for project planning. In this study, the *SafeSecIoT Canvas* artifact represents the practical application of this respective model (M1) for the project planning of a critical IoT system, focusing on translating its abstract elements into real-world descriptions to the project context.

Each component of the *SafeSecIoT Canvas* model (M1) represents a building block in the canvas artifact, which is used to outline the characteristics of the planned IoT system. The building blocks of the artifact – such as objectives, benefits, actions, assets, risks, and others – are applied within the context of a critical IoT system project. Figure 5 presents a template for the *SafeSecIoT Canvas* artifact, showing how each component should be instantiated and utilized in these project types.

In summary, the M0 instance (the artifact) should illustrate how the abstract elements of the canvas model (the components defined in M1) are applied in a real project. This approach ensures that the metamodel (M2), through model M1, is effectively realized in the real world (M0) clearly and measurably, specifically in planning a critical IoT system.

6. Discussion

The *MM4Canvas* metamodel establishes a common language and standardized structure for creating and representing canvas models, promoting consistency and interoperability between models (standardization). It was built with a concise set of concepts and relationships, facilitating straightforward comprehension and utilization for terminal model development, ensuring clarity in understanding metamodel instances (usability). The *MM4Canvas* allows the instantiation of canvas for different purposes and application domains (adaptability) while supporting the extension of general-purpose models to accommodate specific application domains (reusability and extensibility).

We demonstrate the use of the metamodel for instantiating terminal models of canvas for projects, aiming the planning, scope definition, and requirements elicitation to support later stages of the RE process. As proof of concept, we instantiate the PMC (reference model for the project planning) and reuse it as a basis for extending it in *SafeSecIoT Canvas* model, enabling essential critical IoT systems project information to be agile-defined, discussed collaboratively, and provide support for the definition of SSR.

In the Section 5, we show that the model (M1) developed for the PMC, moreover to validate *MM4Canvas* served as a reference model for the development of a new domain-specific model (M1), the *SafeSecIoT Canvas*, and its matching artifact (M0). This model extends the PMC (inheriting its general-purpose components and relationships) and brings domain-specific components required to the IoT systems that address SSR. Likewise, *MM4Canvas* supports the instantiation from everyone else terminal models (M1) previously mentioned in this article (BMC, MVP Canvas, IoT Canvas, ML Project Canvas, and others) and their possible extensions, making it a comprehensive metamodel for canvas.

Furthermore, the *SafeSecIoT Canvas* integrates work in progress [30, 31] for aligning safety and security since the first step in a RE process, comprising the scope definition and initial safety and security requirements elicitation. The goal is to support the alignment of safety and security requirements to avoid, from the initial design stages, system losses caused by known or unintentionally generated hazards or introduced by threats unknown or from intentional sources such as malicious individuals or organizations.

7. Final Remarks

This work presents a metamodel-based approach – named *MM4Canvas* – to support the development of canvas models for different purposes. We define a strategy for abstracting canvas models at a design level that allows describing the relationships between their elements and that support their construction. Through metamodeling, we offer essential methodological support to streamline the creation of canvas models for diverse needs and application domains. This approach also ensures the instantiation of canvas models in a more effective, standardized, and reusable way.

Threats to our study's validity include: i) the lack of an empirical evaluation with stakeholders of real projects; and ii) the PoC was conducted by the authors. Integrating *SafeSecIoT Canvas* into critical IoT systems' safety and security RE process is underway [30, 31]. For this reason, we plan to evaluate the artifacts proposed here in two phases: (i) in academia for possible adjustments and improvements in the methodology, materials, and artifacts that compose it and (ii) with professionals in real projects.

As future work, we highlight i) the quality assessment of the *MM4Canvas* metamodel, e.g., through the *Metamodel Quality Requirements and Evaluation* (MQuaRE) framework [15, 14]; ii) the instantiation of other canvas models (M1) in addition to PMC and *SafeSecIoT Canvas*, both for general purpose and specific application domains; and iii) the use and evaluation of *MM4Canvas* and instantiated models in real projects.

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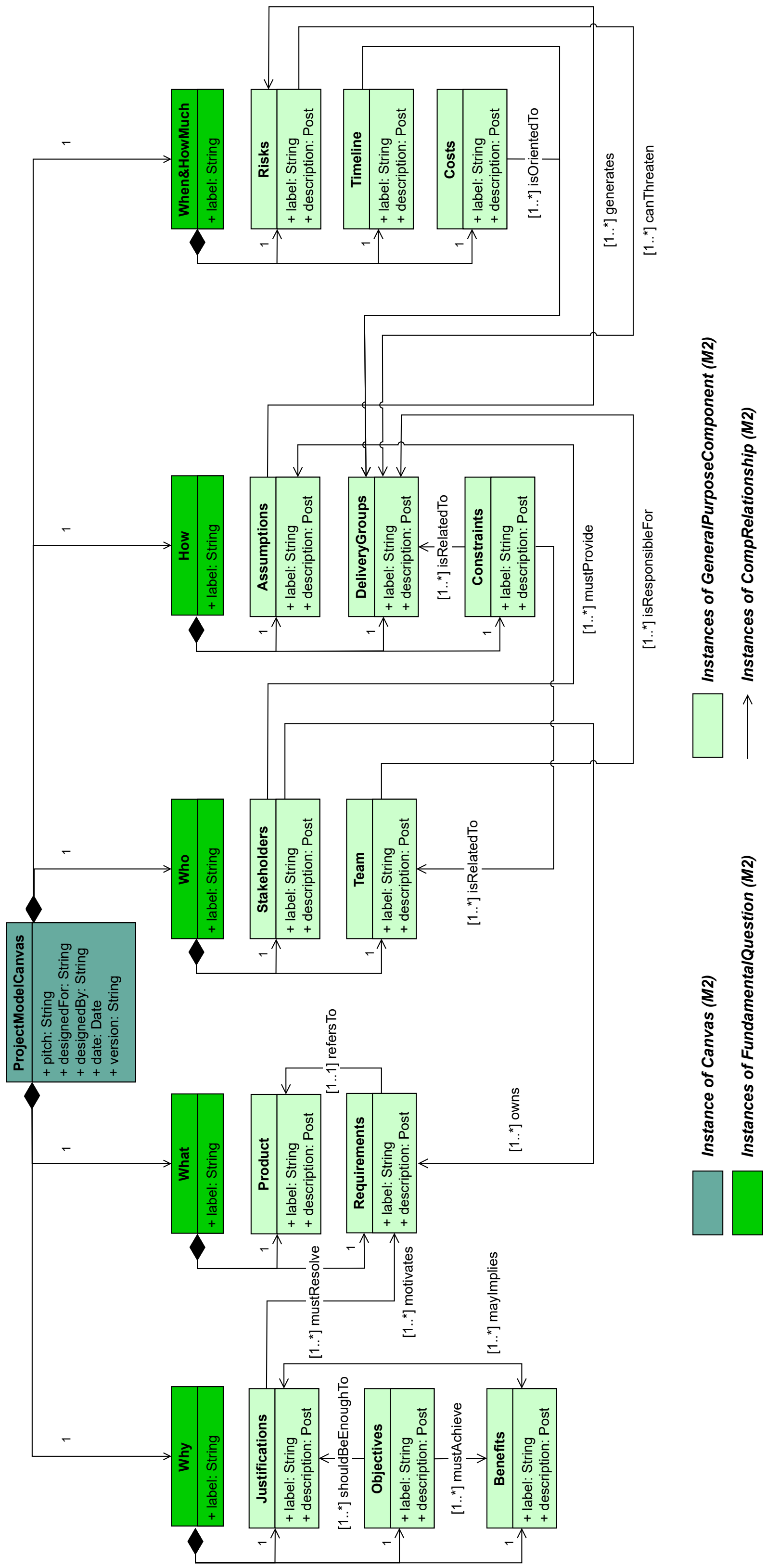

Figure 3. Model PMC (M1): a canvas model for projects (of general purpose), instantiated from the *MM4Canvas* metamodel (M2).

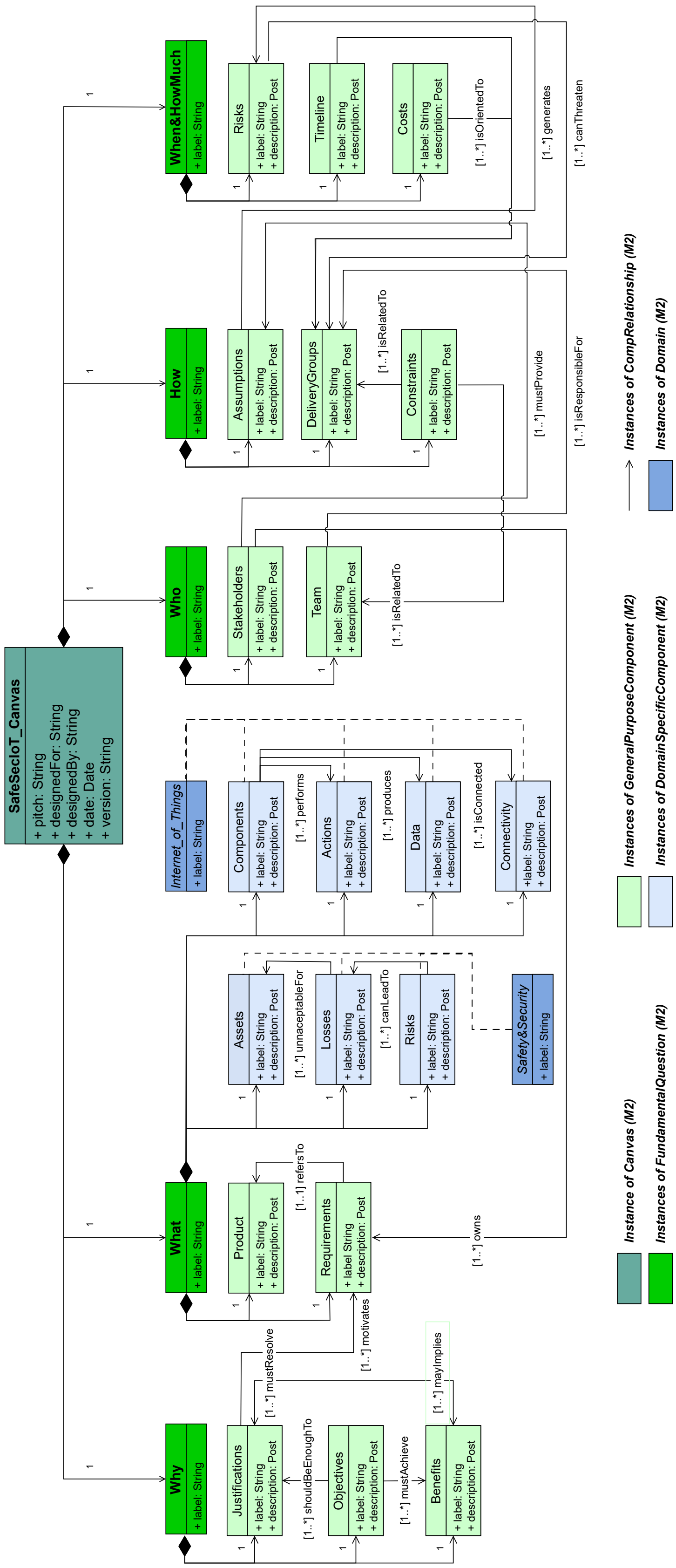

Figure 4. Model *SafeSecIoT Canvas* (M1): a canvas model for critical IoT projects, instantiated from the *MM4Canvas* metamodel (M2) with general-purpose components (reused from PMC model) and IoT and SSR domain-specific components (extending the PMC model).

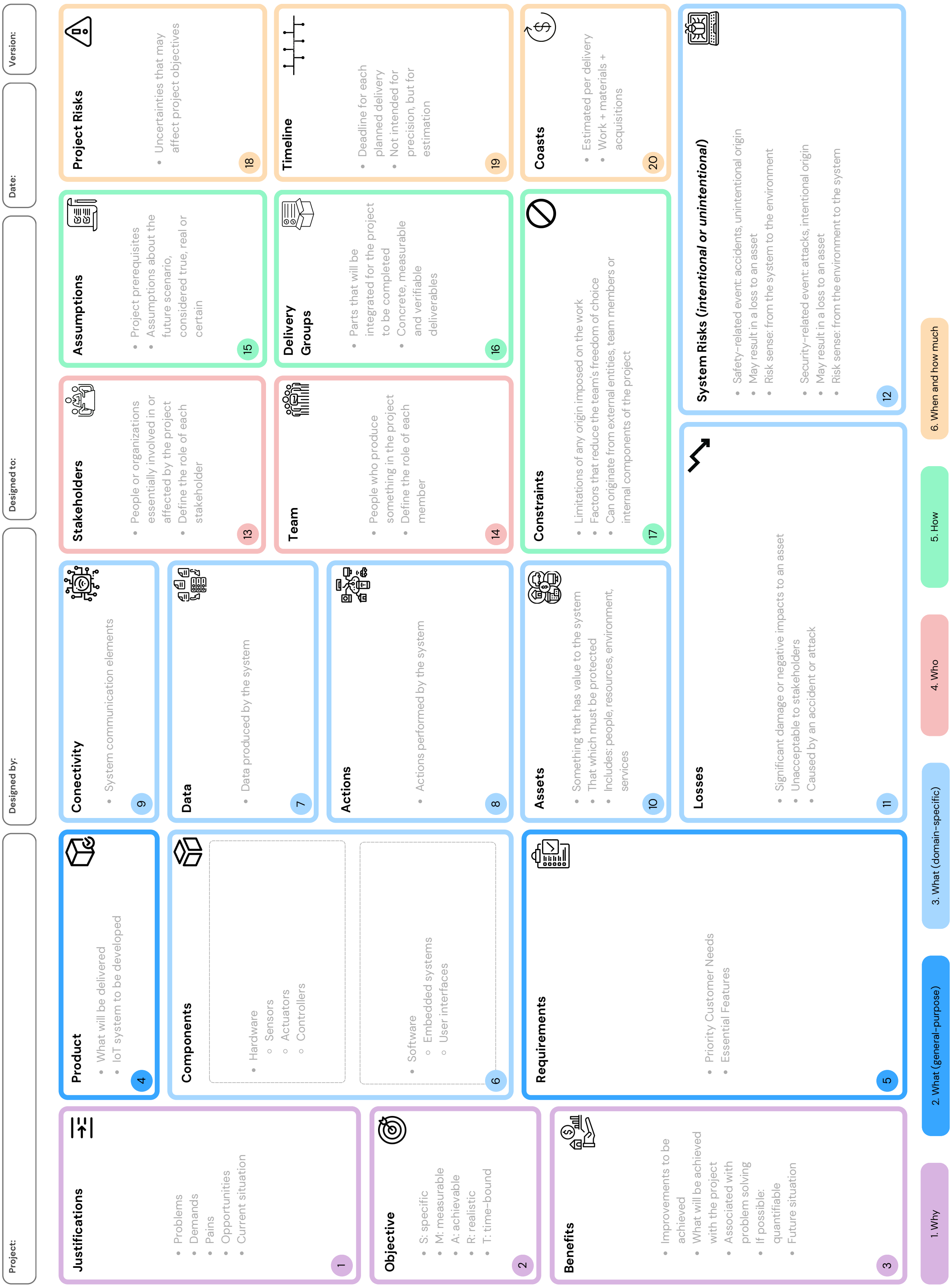

Figure 5. Artifact *SafeSecIoT Canvas* (M0): template for agile project planning.