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Low-code Engineering for Internet of things: A state of research

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ABSTRACT

Developing Internet of Things (IoT) systems has to cope with several challenges mainly because of the heterogeneity of the involved sub-systems and components. With the aim of conceiving languages and tools supporting the development of IoT systems, this paper presents the results of the study, which has been conducted to understand the current state of the art of existing platforms, and in particular low-code ones, for developing IoT systems. By analyzing sixteen platforms, a corresponding set of features has been identified to represent the functionalities and the services that each analyzed platform can support. We also identify the limitations of already existing approaches and discuss possible ways to improve and address them in the future.

CCS CONCEPTS

• Software and its engineering → Model-driven software engineering.

KEYWORDS

Model Driven Engineering (MDE), IoT, Low-code Engineering

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1 INTRODUCTION

According to European Union CONNECT Advisory Forum report [4], IoT promises to be one of the most disruptive technological revolutions since the advent of the Internet as projections indicate that more than 50 billion humans and objects will be connected to the Internet by the end of 2020. As we experience in daily life, now we see more and more intelligent traffic lights, advanced parking technologies, smart homes, and intelligent cargo movement. This is due to the rising adoption of artificial intelligence (AI), and 5G infrastructure is helping the global IoT market register an increased growth.

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In 2018, the IoT market was valued at \$190 billion and it is anticipated to reach \$1,102.6 billion by 2026. The IT industry is rapidly adopting cloud-based solutions, which are contributing to the growth of the market. Even though we see the spike in IoT technologies with much complexities and a huge amount of processing power, there are still even more sophisticated challenges lying behind the implementations of such systems. To highlight a few, IoT is facing a huge scale of heterogeneity in terms of devices, users, data sources, and communication modes that need to be combined to form a fully sensed application. This leads to the issue of standards as new technologies come in and change the game.

The current trend of low-code development platforms (LCDP) catches people's attention due to their capabilities in easing the development of fully functional applications mostly cloud-based. The primary goal of LCDP is to facilitate people with less or no experience in software engineering to develop business applications using simple graphical user interfaces [23]. Lowcomote project [32] aims to push that advancement to a more technical and sophisticated era of "Low-code Engineering" by employing the concrete basic engineering principles to the modeling world. This will be done by the merge of model-driven engineering, cloud computing, and machine learning techniques.

In this paper we want to show the current state of research on model driven engineering approaches for IoT by taking into account low-code development platforms in particular. We present the results and the findings that have been done by analyzing sixteen IoT development platforms. They are divided into two categories considering their basic implementation mechanisms. In particular, the first category consist of tools based on the Eclipse technologies such as Eclipse Modeling Framework(EMF), Graphical Modeling Framework(GMF), and Papyrus environment. The second category is a collection of tailor-made platform referred as low-code development platforms.

The study has been performed in three main steps: first, we conceived a taxonomy consisting of features characterizing the studied IoT development platforms. Then, such features are used to evaluate the functionalities and the services supported by each analyzed platform. As a last step we identified some weakness of the analyzed platforms to pave the way toward a low-code platform for developing IoT systems. We have also identified some limitations of already existing approaches and discuss possible ways to improve and address them in the future.

The rest of this paper is organized as follows: Section 2 makes an overview the IoT engineering core concepts. Section 3 presents the currently available languages and tools supporting the development of IoT systems. Section 4 presents a taxonomy we have defined to support the comparison of the considered IoT development approaches. By relying on the outcomes of the performed comparison, Section 5 discusses the strengths and limitations of

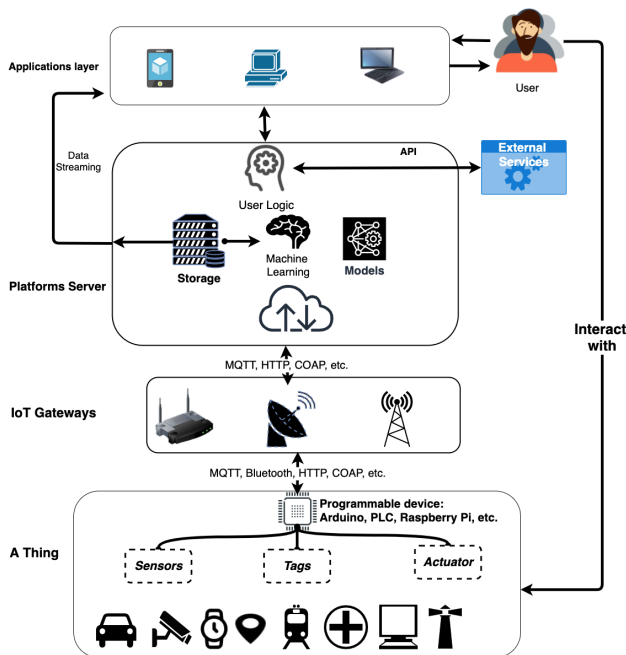


Figure 1: IoT system building blocks

existing approach in order to identify future research directions. Section 6 concludes the paper and mentions some future work.

2 ENGINEERING IOT SYSTEMS

In the past, IoT referred to the advent of bar-codes and Radio Frequency Identification (RFID), helping to automate inventory, tracking, and to support basic identification needs. The current wave of IoT is characterized by a strong verve for connecting sensors, objects, devices, data and applications [3]. A fully IoT system is generally complex and its development typically requires many players of various expertise and several stakeholders with different responsibilities. IoT is regarded as a collection of automated procedures and data, integrated with heterogeneous entities (hardware, software, and personnel) that interact with each other and with their environment to reach common goals [19].

Figure 1 shows a high-level architecture of a typical IoT system. A *thing* is a combination of on-board devices including *sensors*, *tags*, *actuators*, and *physical entities* like cars, watches, etc. Data is generated from a sensor or a tag attached to the physical entity the user is interested in. A computing device (such as an Arduino, a Pycom, a Raspberry Pi, etc.) collects data and send them to the nearby gateway using some well-known protocols such as Z-Wave, MQTT, HTTP, Bluetooth, Wi-Fi, Zigbee, etc.

The *Gateway* component acts as a bridge between the physical and digital worlds. Note that in some cases devices and gateways can make some simple computation logic and respond to some events without the need for further processing. The platform server is a combination of processing and storage resources on the cloud. At this stage, data can be streamed, analyzed, or manipulated for

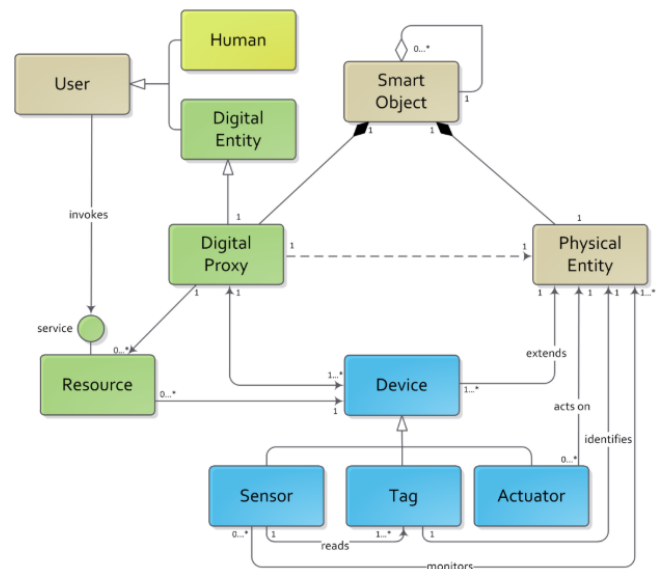


Figure 2: IoT conceptual metamodel [24]

meaningful information to be communicated back to actuators, users, or third parties services.

To support the development of complex IoT systems, several standards and tools have been proposed over the last years [20]. Standards like ISO/IEC/IEEE 15288¹ have been in use to evaluate the quality, efficiency, life-cycle of different approaches. In [33] an IoT reference model (ITU-T Y.2060)[10] is proposed by an International Telecommunication Union (ITU) and presented with respect to other four reference architectures developed in the context of the IoT-A [3], WSO2 [8], Korean RA [10] and Chinese [5] projects.

Figure 2 shows a conceptual representation of the elements shown in Figure 1. The physical properties of the associated *Physical entities* are captured through *Sensors*, whereas the modification of physical properties of associated *Physical Entity* is performed through the use of *Actuators*. *Physical Entity* can be represented in the digital world by a *Digital Entity* which is in turn a *Digital Proxy*. *Digital Proxy* has one and only one *ID* that identifies the represented object. The association between the *Digital Proxy* and the *Physical Entity* must be established automatically. A *Smart Object* has the extension of a *Physical Entity* with its associated *Digital Proxy* which then talk to the user through by providing or requesting resources. The external services are invoked by the user which can be human or third-party software.

3 IOT DEVELOPMENT APPROACHES

This section makes an overview of languages and tools to develop IoT systems by distinguishing those that implement modeling principles from proper low-code development platforms. The purpose of this study is to highlight the current state of the art in model based development for IoT systems. To ensure the authenticity of our search, we have conducted the search following the three main steps as listed below.

¹<https://www.iso.org/standard/63711.html>

First, we conducted a manual search on google scholar² using keywords such as “*Model driven engineering IoT*”, “*MDE IoT*”, “*Model driven engineering Internet of Things*”, and “*MDE Internet of Things*”.

Second, we manually analysed and selected the papers following the content in the abstracts and conclusions. Note that we were more interested in tools that can sell on the market not just approaches with some minor implementation. To this end, we have selected approaches satisfying the following criteria:

- (1) Availability of supporting tools;
- (2) More recent than 2010;
- (3) Use of MDE as underlying technique;
- (4) Referred by at least three scientific publications.

Third, we conducted a paper mapping phase starting on the approaches found in the previous step. We mostly considered what approach a paper refers to or what refers to it. This was not an easy task. We went manually through each of the selected approaches by consulting through several publisher sites such as IEEE, ACM and Springer. This manual search was basically conducted using the tool’s name as the main searching keyword.

On the lowcode development side, we mainly considered the LCDPs selected in a recent Gartner report [34] that focuses on promising low-code platforms. We have also added a few LCDPs obtained by conducting a manual search on google using “*Lowcode Development platform IoT*”, and “*Lowcode Development platform Internet of Things*” keywords. The “*Lowcode development platform*” is a more recent term, the results found were mostly present in [34]. The additional LCDPs was selected due their popularity and the fact that they are capable of implementing the basic IoT elements depicted in Fig. 1.

3.1 MDE approaches

This section presents an overview of modeling languages and supporting tools that authors have identified by analyzing existing literature in the MDE research field.

MDE4IoT framework [29]: It is a tool to support the architectural modeling and self-adaptation of emergent configurations regarded as Things. This approach was validated by modeling the Smart Street Lights use case [29]. MDE4IoT is a combination of different UML Domain Specific Languages as profiles and validated code generators. MDE4IoT uses a combination of different viewpoints to capture the system functionalities from hardware to software which help to accurately perform model-to-model transformations. The approach relies on the UML-MARTE profile for modeling hardware components as well as allocations of software to hardware. Run-time adaptations are meant to be performed automatically by specific in-place model transformations.

SysML4IoT [20]: It is a SysML profile based on the IoT-A reference model presented in [3]. The *SysML2NuSMV translator* is also available to generate NuSMV³ specifications out of input SysML models with the aim of supporting the verification of Quality of Service (QoS) properties by taking into account environmental constraints. SysML4IoT has been adopted in [19] in the context of the *IDEA-IoT DevProcess & AppFramework*. The IoT DevProcess has

been extended from OOSEM⁴ standards and tailored to support IoT application design. To support the activities of IoT DevProcess through SysML4IoT, all hardware devices and software components are precisely identified in the system model as stereotypes. The same tool has been adopted in [9] to develop IoT self-adaptive systems endorsing the public/subscribe paradigm to model the communication with other systems.

Papyrus for IoT [7]: It is a modeling tool based on Papyrus. The approach has been already used to develop a smart IoT-based home automation system as a benchmark application to showcase the capability of the solution. Authors suggest the extension of Papyrus Moka⁵ to perform model simulations. Concerning the deployment of the modeled systems, authors make use of Prismtech’s Vortex as a dynamic platform to discover and deploy microservices, and MicroEJ as the target operating system.

UML4IoT [31]: It is an MDE based tool developed for industrial automation systems (IASS). A model-to-model transformation has been developed to automatically transform the mechatronic components to Industrial Automation Things (IAT). UML4IoT has been exploited to automate the generation process of the IoTwrapper, a software layer that is required on top of the IEC61131⁶ cyber-physical component to expose its functionality to the digital IoT ecosystem. The authors developed a LWM2M application protocol running on top of the CoAP communication protocol.

IoTML [6]: It is a tool developed in the context of the BRAIN-IoT project⁷. BRAIN-IoT presents an integrated modeling environment to ease the rapid prototyping of smart cooperative IoT systems based on shared models. The BRAIN-IoT architecture mainly consists of three macro-blocks: the BRAIN-IoT modeling Framework, the Marketplace, and the federation of BRAIN-IoT Fabrics. The BRAIN-IoT modeling environment includes the IoTML modeling tool, which is implemented as a Papyrus profile. The IoTML tool permits to specify models that can be uploaded to the BRAIN-IoT marketplace to foster their future reuse.

IoTLink [21]: It is a development toolkit based on a model-driven approach to allow inexperienced developers to compose mashup applications through a graphical domain-specific language. Modeled applications can be easily configured and wired together to create an IoT application.

To support interoperability with other services, authors implemented custom components like ArduinoSerial for Arduino connectivity, SOAPInupt, RESTInput, MQTTInput, etc. At runtime, the tool generates connections by using the Drools⁸ engine to poll the rules from a database repository, which allows developers to deploy and change deployment rules at runtime.

FRASAD [17]: It is a model driven framework to develop IoT applications. FRASAD relies on a node-centric software architecture and a rule-based programming model. FRASAD has been developed atop of Eclipse EMF/GMF and consists of a graphical modeling

²<https://scholar.google.com/>

³<http://nusmv.fbk.eu/>

⁴<https://www.incose.org/incose-member-resources/working-groups/transformational/object-oriented-se-method>

⁵<https://wiki.eclipse.org/Papyrus/UserGuide/ModelExecution>

⁶<https://plcopen.org/iec-61131-1>

⁷<http://www.brain-iot.eu/>

⁸<https://www.drools.org/>

language, a code generator and other supporting tools to help developers design, implement, optimize, and test the developed IoT applications.

ThingML [15]: It consists of a modeling language and supporting tools already employed to develop commercial e-health solutions [15]. The ThingML language combines well proven software-modeling constructs aligned with UML (statecharts and components) and an imperative platform-independent action language to construct the intended IoT applications. The tools include an advanced multi-platform code generation framework that supports multiple target programming languages such as C, C++, Java, Arduino and JavaScript. The tool is open to the community as an Eclipse plugin.

ThingML+ [13]: It is an extended version of the ThingML tool [15] designed for IoT/cyber-physical systems with the aim of addressing machine learning needs. The authors presented a new approach of using machine learning techniques to tackle the issue of IoT communications and behavioral modeling which was normally being done using state machines. The techniques have been integrated at the modeling level and code generation level. The approach has been developed in the context of the ML-Quadrat⁹ research project.

AutoIoT [16]: It is a framework that allows users to model their IoT systems using a simple JSON file. The process starts by modeling the system using the graphical interface generated from GMF. When the modeling phase is completed, AutoIoT loads the content of the model as a JSON file to be validated and transformed into Python objects using the Pydantic¹⁰ library. After that, the framework finally delivers these objects to an appropriate *Builder* that performs model-to-text transformations to generate a ready-to-use IoT server side application. The Prototype Builder generates a Flask application written in Python, HTML, CSS, and Javascript. The generated server-side application communicates with IoT devices and third-party systems through MQTT, Rest API, and WebSockets.

IoTSuite [28]: It is a tool suite consisting of the following components: *i)* an *editor* to support the application design phase by allowing stakeholders to specify high-level descriptions of the system under development; *ii)* an ANTLR¹¹ based *compiler* that parses the high-level specification and generate an IoT framework; *iii)* a *deployment module*, which is supported by mapper and linker modules; *iv)* a *runtime system*, which leverages existing middleware platforms and it is responsible for the distributed execution of the modeled IoT application. The current implementation of IoTSuite targets both Android and JavaSE-enabled devices and makes use of an MQTT-based middleware.

CAPS [25]: It is an architecture-driven modeling tool based on Eclipse EMF/GMF designed to enable architects, system engineers, and cyber-physical space designers to capture the software architecture, hardware configuration, and physical space into views for a situational-aware CPS. To link together the modeled views, the authors introduced two auxiliary languages, denoted as Mapping Modeling Language (MAPML) and Deployment Modeling Language (DEPML). The authors used the Atlas Model Weaver

(AMW)¹² to define relations among models and to create semantic links among model elements. The tool also has a *CAPSml* code generation framework built on top of the CAPS modeling framework which transforms the CAPS model into ThingML [15] code which can then be used by the ThingML framework to generate fully operational code.

Authors in [22] present a domain-specific language that can be used to model the structural and behavioral views of a smart city application. A metamodel was developed using EMF and the graphical interface of the DSL was generated using GMF. In their work, the authors used OCL (Object Constraint Language) to define constraints and uniqueness of elements in a model by introducing element rules. The approach fosters also the adoption of a repository of already modeled elements by taking care of device definitions and configurations.

In [30] authors present a DSL designed to specify all aspects of a sensor node application, especially for data processing tasks such as sampling, aggregation, and forwarding. The proposed DSL offers a set of declarative sentences to express the behaviour of sensor nodes application such as *sampling*, *aggregating*, and *forwarding* which is necessary for developing data-centric Wireless Sensor Network (WSN) applications. The tool is based on Eclipse GMF for specifying PIMs. The transformation from the PIM to nesC¹³ PSM models has been implemented by using the ATL transformation language¹⁴. Acceleo-based model-to-text transformations have been developed to generate final nesC source code of the modeled system.

3.2 Low-code development platforms for IoT

Low-code development platforms (LCDPs) aim at bridging the gap between experienced software developers and people with less or no experience in software engineering. LCDPs have shown their strengths in the development of software systems in four main market segments such as database applications, mobile applications, process applications, and request-handling applications. According to [32], IoT will be the next market segment for LCDPs. In this section, we make an overview of existing LCDPs for IoT that take into account MDE concepts in their core implementations.

Node-RED¹⁵ is a programming tool specifically conceived in the IoT context, with the aim of wiring and connecting together hardware devices, APIs, and online services [18]. It provides a cloud-based editor that makes it easy to connect together flows using the wide range of nodes in the palette that can be deployed to its runtime easily. Node-RED provides a rich text editor built on top of Node.js taking full advantage of its event-driven, non-blocking model. Node-RED can be run locally or on the cloud. Node-RED is platform agnostic and compatible with several devices such as Raspberry Pi, BeagleBone Black, Arduino, Android-based devices. Node-RED also supports its integration with cloud-based resources such as IBM Cloud, SenseTecnica FRED, Amazon Web Services, and Microsoft Azure.

⁹<https://www.quadrat.ac.uk/quadrat-projects/>

¹⁰<https://pydantic-docs.helpmanual.io/>

¹¹<https://www.antlr.org/>

¹²<https://projects.eclipse.org/projects/modeling.gmt.amw>

¹³<http://nescc.sourceforge.net/>

¹⁴<https://www.eclipse.org/at/>

¹⁵<https://nodered.org/>

AtmosphericIoT¹⁶ provides IoT solution builders with languages and tools to build, connect, and manage embedded-to-cloud systems [1]. Atmosphere IoT Studio offers a free drag-and-drop online IDE, to build all device firmware, mobile apps, and cloud dashboards. AtmosphericIoT connects devices from a range of wireless options including Wi-Fi, Bluetooth and BLE, Sigfox, LoRa, ZigBee, NFC, satellite, and cellular. This platform is entirely cloud-based but it offers downloadable artifacts.

Simplifier¹⁷ is a low-code Platform for integrated business and IoT applications that enable user to create, manage, deploy, and maintain enterprise-grade SAPUI5¹⁸ apps for web, mobile, and wearables. Simplifier uses a pre-built interface for bidirectional integration of existing SAP and non-SAP systems and leverage shop-floor integration with native IoT-interfaces (OPC-UA, MQTT) [27]. It is provided as a web-based environment available on-premise or in the cloud. Simplifier permits to deploy applications on SAP Cloud Platform, SAP NetWeaver, as stand-alone, or on a dedicated Simplifier cloud.

Mendix¹⁹ is one of the popular low-code development platforms that offer significant enterprise characteristics especially attractive to large businesses[34]. Its platform is equipped for multi-cloud and hybrid computing, due to its support for on-premises, virtual private multi-cloud, and multitenant public cloud deployment options [12].

Salesforce²⁰ is a popular CRM low-code development platform that has been adopted through many different new technologies like AI, Machine Learning, and Cloud computing. Salesforce supports the rapid prototyping of IoT applications through the connection with the underlying Salesforce IoT cloud engines [11]. This platform provides data visualization and event management through a visual set of rules and triggers on different data source components.

4 TAXONOMY

In this section we introduce a taxonomy of terms, which can support the description and the comparison of different approaches for the development of IoT systems. By analyzing the languages and tools overviewed in the previous section, we identified and formalized their corresponding variabilities and commonalities in terms of a feature diagram.

These features were selected mainly based on the common understanding regarding the stages to be followed in the software development process, from requirement definition, system design, development, deployment and maintenance of a robust complex system. This was an iterative process where all authors were involved in the development of the proposed taxonomy. Findings related to the performed study are discussed in the next section.

Figure 3 shows the top-level feature diagram, where each sub-node represents a major point of variation. Table 1 gives details about the taxonomy described in the following.

Requirement modeling support: this group of features emphasizes the first stages of any MDE based development process. This evaluates whether a tool have an inbuilt requirement specification

environment. Supporting this feature is very important because it helps keep track on whether the specified requirements are correctly implemented throughout the whole development. This also helps in requirements traceability and verification.

Domain Modeling support: it refers to the kind of modeling tools the user is provided with e.g., if it is graphical or not, if it gives the possibility to model the static structure of system’s blocks or components. Some of the analyzed systems provide modelers with behavior modeling capabilities to specify semantic concepts relating to how the system behaves and interacts with other entities (users or other systems). For instance, OMG based implementations of UML/SysML inherits all the modeling functionalities which include structural and behavioral diagrams. Additionally, we looked at if the tool can support system modeling through multiple view which in turn is considered as multi-view modeling support.

Testing and verification support: It refers at whether a tool has inbuilt mechanisms to evaluate artifacts before deployment which can be done by conducting different verification checks. To be more specific this feature examines if the tool has a testing workbench, an inbuilt model checking and validation facility. This is very important as it ensures the system correctness and robustness which make system safe and secure. As IoT applications are in our everyday life, we are interested in developing systems that will causes no harm to users in case of a more and more sophisticated scenarios.

Analysis environment: such a group of features is related to the capability of the considered environment to support different analysis checks for the intended system before its deployment. This can be done on different blocks or components of the system by checking on their responsiveness in case of failure, network loss, security breach, and so on. In this regard, we can feature dependability analysis, real-time analysis, and system quality of service in general.

Reusability: this category illustrates whether the tool under analysis allows the export of artifacts for future reuse. This can be

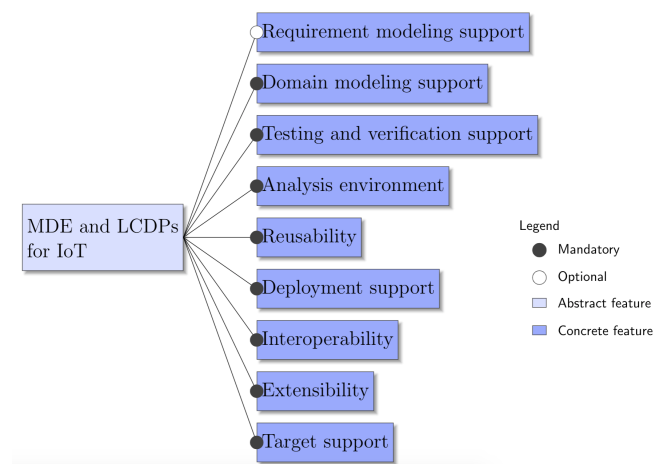


Figure 3: Feature diagram representing the top-level variation areas

¹⁶<https://atmosphereiot.com/>

¹⁷<https://www.simplifier.io/en/>

¹⁸<https://www.guru99.com/sapui5-tutorial.html>

¹⁹<https://www.mendix.com/>

²⁰<https://www.salesforce.com/>

done on developed models or on generated artifacts. Reusability features are also related to the way artifacts are managed e.g., locally or by means of some cloud infrastructure.

Deployment support: it is related to the ways developed systems are deployed and if in general generated artifacts are ready for deployment or not. To the best of our knowledge, this should be one of the important features to focus on when implementing a novel tool. We also looked at whether the development tool can be installed locally or on the cloud depending on client's interest. Finally, we looked on whether the tool or platform provides runtime adaptation mechanisms (on modeled or generated artifacts) to respond to contextual changes and thus, react accordingly.

Interoperability: this feature examines the ability of a tool to exchange information either internally between components, expose or consume functionalities or information from external services e.g., by means of dedicated APIs.

Extensibility: the tool should provide the means for refining or extending the provided functionalities. In the case of modeling tools, such a feature is related to the possibility of adding new modeling features and notations.

Target Support: It refers to the characteristics of the target infrastructure, which enables the execution of the modeled system. Sub-features are represented by the *underlying infrastructure* to exhibit the core technologies a tool relies on, *target platform*, which presents different devices and platforms supported by the generated code, and *code generation language* to refer the programming languages supported by the considered system.

Further than the previous features, we identified "**additional characteristics**" that are orthogonal to the previously discussed elements. In particular, some tools target early phases of development like system design, data acquisition, system analysis by focusing on the *thing* behaviour. Some other tools target the application generation without taking much care of the data acquisition phases which can be done by integrating the developed system with already implemented data source engines, etc. Another peculiar aspect is if the considered approach is available as open source or not having this an important impact on the possibility for the community to contribute to its development.

5 FINDINGS

The elicited features, which have been discussed in the previous section, have been considered to study and analyze 16 platforms. The selection has been done by considering all the platforms that cover the IoT modeling domain. According to Table 1 most of the analyzed approaches rely on Eclipse and OSGi. We have realized a huge lack of focus on requirement specification except for SysML4IoT (as it extends SysML which enforces requirement specification) and FRASAD, which enforces the requirement specification at the PIM level using rules that can be tracked throughout. The huge lack of analysis support for almost all the tools selected is alarming. We think that it is highly important to analyze and verify the intended system's behavior before deployment as it gives developer indications of what may happen before deployment and help make any adjustment earlier enough. Moreover, we can see that most of the analyzed tools can be deployed locally especially concerning EMF-based tools but mostly all LCDPs are cloud-based

with some of them being able to be run also locally. The main weakness that we discovered by the performed analysis are described below.

Lack of standards: we noticed a lack of a standards to support the model-based development of IoT systems. We noticed that each tool proposes its own way of development by hampering interoperability possibilities among different platforms. This is due to the presence of many industrial players, which make the IoT meta-modeling convoluted. On the other hand, different research attempts proposed IoT reference models, which cover different development phases and perspectives. The IoT reference model presented in [3] has been adopted by different tools [7, 20, 21] as a fundamental meta-model. This shows the potentials and benefits of having the availability of standards in such a complex domain. We believe that it as a good starting point, which needs to be further explored to better cover the interoperability dimension (e.g., to enable the possibility of interacting with third-party data resources in general).

Limited support of multi-view modeling: we noticed that most of the approaches focus on single view modeling. In particular, except for CAPS, MED4IoT, Atmospheric IoT, and Mendix, the analyzed approaches use one specific view to model everything, which is not a good practice in general. Using multi-view modeling presents enormous benefits as it enforces separation of concerns: the system component is designed using a single model with dedicated consistent views, which are specialized projections of the system in specific dimensions of interest [26]. Multi-view modeling is regarded as a complicated matter to address for tailor-made low-code development platforms as they mostly focus on connecting dots aiming at having an application up and running.

Limited support for cloud based model-driven engineering: Moving model management operations to the cloud and supporting modeling activities via cloud infrastructures in general is still an open subject. From our study, we noticed that mostly low-code development approaches provide the option to run tools on cloud or on-premise. This is not yet the case of tools based on Eclipse EMF, which still requires local deployments. The research presented in [14] proposed a DSL as a Service (DSMaaS) as a solution to address the reusability of so many created DSL over the cloud. Other attempts like MDEforge²¹ aim at realizing cloud based model manipulations [2].

Limited support for testing and analysis: According to the performed study, very few tools care about the testing and analysis phases of the IoT system development process. There is still a big challenge regarding how to analyze IoT systems responsiveness before deployment. The complexity of the problem relies on the fact that IoT system involve human interaction, environment constraints and we have also to recognize the heterogeneity of the target platforms that makes it hard to depict the kind of analysis properties to address.

The above table and discussed findings should not be considered as a final reference but it should give a sense on the state of research in MDE based IoT development platforms. This is because we relied on published papers and official documented work which

²¹<http://www.mdeforge.org/>

	MDE Approaches											Lowcode development platforms				
	BRAIN-IoT/ IoTML	MDE4IoT	Papyrus4IoT	SysML4IoT	UML4IoT	ThingML	IoTLink	IoTSuite	FRASAD	AutoIoT	CAPS	NodeRed	AtmosphereIoT	Simplifier	Mendix	Salesforce
Requirement modeling support																
Requirement specification				✓					✓					✓		
Requirement verification																
Domain modeling support																
Graphical user interface	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Structure model	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Behaviour model	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Multi-view modelling	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Testing and verification support																
Testing environment									✓			✓		✓	✓	✓
Model checking	✓			✓		✓					✓					
Model validation	✓		✓			✓					✓					
Analysis environment																
Realtime analysis																
Dependability				✓												
System QoS				✓							✓			✓		
Reusability																
Allow exporting artifacts	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Allow importing external artifacts											✓					✓
Allow artifact storage and future reuse	✓	✓				✓		✓			✓		✓	✓	✓	✓
Deployment support																
Can be deployed locally	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Can be deployed on cloud	✓					✓					✓		✓	✓	✓	✓
Can generate code	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Run-time adaptation	✓	✓	✓	✓	✓	✓	✓	✓			✓					
Interoperability																
Support API integration					✓		✓				✓	✓	✓	✓	✓	✓
Support connect to extern data sources	✓				✓		✓				✓	✓	✓	✓	✓	✓
Extensibility																
Easy to add modeling features	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Easy to modify the existing features	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Additional characteristics																
Focus on "The thing" layer	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Focus on Application layer						✓					✓					✓
Open source to developers	✓		✓			✓					✓					✓
Target support																
Underlying infrastructure	Papyrus OSGI	Papyrus	Papyrus	Papyrus, Moka	Papyrus	EMFCore Maven	EMF, GMF, EEF, Acelelo, Esper	xText, ANTLR, J2SE	EMFCore GMF	EMF, GMF	EMF,GMF, AMW, ThingML	NodeJS	Java	Node.js, Docker	Java, JS, AWS	Java, Salesforce IoT Cloud
Target platform	IoTboards, cloud servers	IoT boards	MicorEJ, Prismtec h's Vortex	MicroEJ, Edison board	Contiki, Rasp. Pi	IoT Boards, OS, Cloud	Arduino	Android, J2SE platforms	TinyOS, Contiki	cloud	Same target as ThingML	platform agnostic	Mobile, Many IoTBoard	OS, Android	Cloud	Cloud
Code generation language	Java OSGI artifacts	Java, C++	Java	Java	C	C/C++, JavaScript, Java	Java	Java	C, nesC	Python, HTML, CSS, JavaScript	thingml	None	Java,c, arduino	HTML, CSS, JavaScript	Java, JavaScript	Java

Table 1: Taxonomy table

is considered as authentic but in some cases does not provide the full information on tool capabilities.

6 CONCLUSION AND FUTURE WORK

Model-driven engineering aim is to tackle different challenges faced in design, development, deployment, and run-time phases of software systems through abstraction and automation. In this study, we discussed state of the art on existing approaches supporting the development of IoT systems. In particular, we focused on languages and tools available in the MDE field and the emergent low-code development platforms covering the IoT domain. The analysis has been performed by conceiving a taxonomy, which has been formalized as a feature diagram presenting all the features of a typical modeling platform supporting the development of IoT systems. Different limitations have been identified in the analyzed platforms. As a future work, we want to continue the investigation on model driven engineering based IoT platforms by considering both the quantitative and qualitative aspects of the solutions developed following the two main development approaches presented in 3. In the context of the Lowcomote project, we aim at addressing the presented limitations, especially by focusing on the early analysis

possibilities that a low-code platform should provide to develop secure and trustworthy IoT systems.

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