Model Driven Requirements Engineering: Mapping the Field and Beyond

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***Abstract*—Model Driven Engineering (MDE) holds the promise of raising the level of abstraction when designing systems by promoting domain specific modeling languages, model transformation techniques and code generation engines. Although requirements engineering (RE) relies on models and on modeling, RE and MDE have evolved separately and in distinct communities. The goal of our ongoing work is to analyze the state of the art regarding the convergence and evolution of MDE and RE. This paper is a preliminary study in which we review all papers published at MoDRE workshops and map them according to three perspectives: research issue, research contribution and evaluation method. Our analysis indicates clear predominance of proposals of new language for requirement representation and the derivation of system specifications. Other facets such as requirements elicitation and requirements validation methods are much less tackled, and traceability is seldom discussed.**

***Index Terms*—Mapping study, Literature review, Model Driven Engineering, Requirement Engineering.**

I. Introduction

Ever since the beginning of computer science, an essential research endeavor is to raise the level of abstraction for analysts, engineers and developers when designing and building software systems. The advance of programming languages has been a fruitful trend for decades; however, the introduction of the Entity/Relationship notation for data base design in late 1970' paved the road for conceptual and system modeling [1][2][3]. Since then, a large set of modeling notations and techniques were proposed to deal with various information systems and software engineering issues. Model Driven Engineering (MDE) and Domain-Specific Models and Languages (DSML) are significant effort in this direction. They share a common goal: to bring modeling languages and tools closer to user understanding of the problem he wants to solve and bridge the gap between a domain expert's view of a software system and its implementation [4][5].

Meanwhile, requirements engineering (RE) emerged as a accompanying discipline to face the imperative necessity of defining problem scope, eliciting user needs and goals and establishing a consensus among stakeholders considering system functionalities and boundaries [6]. Although requirements are often expressed in natural language [7], modeling has long been used to represent and reason upon requirements [6]. Models are employed to structure, communicate and/or formalize requirements; they are also used as drivers to prompt further data during the elicitation phase.

It is important to mention here a slight distinction concerning *what* is being modeled. There is indeed a tension between requirements models as expression of the *problem space*, i.e. entirely elaborated in terms of user and system environment [8]; and as specifications in the *solution space* expressing at high level of abstraction what the forthcoming artifact will do, with no concerns about how it will be done [6]. As RE deals with both spaces [7], modeling techniques are used in both, even if certain techniques, i.e. UML activity diagram, are more suited to the solution space, while for the problem space, goal modeling for example is better suited.

This distinction between *problem* and *solution* spaces in RE can be related to the separation between CIM (Conceptual Independent Model) and PIM (Platform Independent Model) levels in MDE. Indeed, a founding principle for MDE is that everything in the engineering process is a model [10]. Models are defined by means of other models, i.e. meta-models, and models at lower level of abstraction are obtained by transforming higher level models. Transposed to RE research issues, and at first sight, MDE can be seen mainly as a technique to derive an implementation out of system requirements, and that could be extended to derive models in the *solution space* out of models in the *problem space*.

Undeniably, applications of MDE approaches to solve RE problems has been explored since more than a decade [9]. However, the range of research issues in RE is not limited to the derivation of implementations out of requirements. Challenges are indeed multiple in RE: elicitation, representation, verification and validation, traceability between artifacts, etc., [6][8]. MDE is indeed a powerful paradigm, and we consider that it has the potential to develop new and innovative approaches and solutions to RE challenges.

This study is a first step of an ongoing research endeavor that seeks to build a comprehensive review of MDE contributions to RE. In this paper, we analyze all papers presented at the Model Driven Requirements Engineering (MoDRE) series of workshops. Our goal is to get a first picture of the literature and pave the way for future work.

We found in the literature two studies that tackle a similar issue. In [9], the authors want to synthesis which RE techniques are employed in model-driven development and their level of automation. In [11], the research question is more tight as the authors want to characterize the different manners by which requirements are integrated into a MDE approach. The work presented here provides a complementary point of view as we investigate the extent to which MDE paradigm is leveraged to solve RE research issues. Furthermore, the focus of our analysis is deliberately limited to papers published at MoDRE workshop series. Our goal is to provide support for discussion concerning what has been investigated at MoDRE workshops and which directions of research should be privileged.

The structure of this paper is the following: in the next section, we present briefly the methodological process followed in this study. In section 3, we present and discuss the results and finish with a brief conclusion in section 4.

II. METHOD

The methodological background for conducting this study is guidelines for Systematic Literature Reviews [12]. However, there is an important differentiating factor here which the strict delimitation of the scope of the review. We systematically analyze – without any exclusion – all papers published at three MoDRE workshops in years 2011, 2012 and 2013; the list of these 29 primary studies is presented in Appendix 1. For the extraction phase, we develop a set of items to be extracted. These items are organized in three groups according to three research sub-questions that this study seek to analyze:

- What are the RE research issues that are tackled by the set of primary studies ? Based on [6] and [8] and inspired by [9] and [11], we define six non-exclusive possible answers depending on the RE task – or goal – that is targeted by the primary study (c.f. Table 1).
- What are the MDE techniques that are developed in the primary study and presented as a research contribution to solve the RE research issue? Based on [9] and [11], we define six non-exclusive possible answers (c.f. Table 1).
- How is evaluated the proposed approach? We define three possible values; other values, i.e. survey, action research, etc., were discarded as they were not encountered in the set of primary studies.

The definition of these items was done iteratively: an initial set of items was tested on a subset of primary studies and then refined and applied on another subset. The final version was obtained after three iterations.

For each MoDRE paper, i.e. primary study, we check which of these items apply. As the items are not exclusive, a primary study can tackle more than one research issue, i.e. *representation* and *derivation*, and the contribution can be multiple, i.e. a *transformation technique* and a *software tool*. For the evaluation part, all primary studies reported one single evaluation method. Finally, for each paper we extracted the requirements category that is dealt with (*Functional*, *Non-Functional* or *both*) and the requirements *application domain*.

TABLE I. ITEMS OF KNOWLEDGE TO BE CHECKED

Item		Definition and explanation
Research issue targeted	Elicitation	1st step in RE process, it deals with requirements identification, extraction and interpretation.
	Representation	The construction of abstract descriptions of requirements, amenable to interpretation, using one or more modeling notation(s).
	Verification and validation	The process of establishing that requirements and models elicited provide an accurate account of stakeholders needs, goals and constraints.
	Traceability	Mentioned in [6] under the topic "*Communicating req.*" and under the topic "*Req. management*" in [8], we consider it as a research issue per se since its importance in dealing with change impact analysis and the opportunities for automation offered by MDE [13].
	Derivation	This issue is specific to RE meeting MDE, it deals with obtaining, manually or automatically, other artifacts, e.g. complementary or lower level models, prototypes, implementations, etc.
	RE process	Called "Integrated Req. Eng." in [6], we check this issue when the primary study deals with RE process as a whole, or when it considers it as a subject of study per se.
Research contribution	Modeling language	Definition of a new modeling notation to represent the requirements and/or to deal with any other research issue.
	Software tool	Proposal of a software tool to fully or partially support the proposed approach.
	Engineering method	Proposal of new methodological approach, represented in a schema or a model and eventually described in some forma manner.
	Transformation technique	Definition of technique to transform models, in the form of informal or formalized rules.
	Traceability technique	Definition of an adapted technique to build, manage and/or exploit traceability links.
	Analysis study	Called "*Evaluation-based research*" in [8], the goal is to critically assess, compare or evaluate the state of practice and/or the state of the art.
Evaluation method	Case study	The approach is applied in an industrial setting, or is illustrated on a case derived from an industrial partner.
	Controlled experiment	The approach is tested with an experiment conducted according to specific controllable conditions [14].
	Illustration	The approach is applied on a "toy" example.

III. RESULTS AND DISCUSSION

To begin, Fig. 1 displays descriptive statistics concerning the requirements category and the application domain.

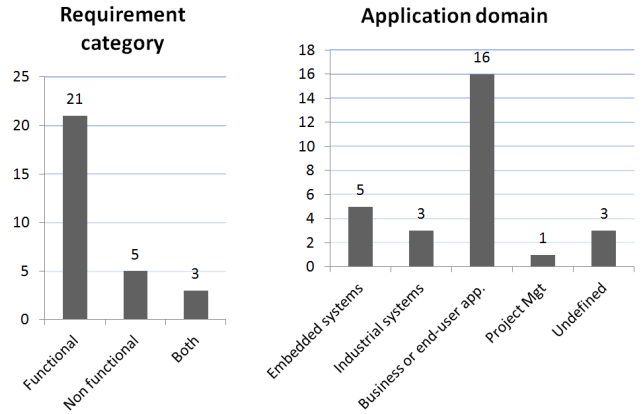

Fig. 1. Descriptive statistics

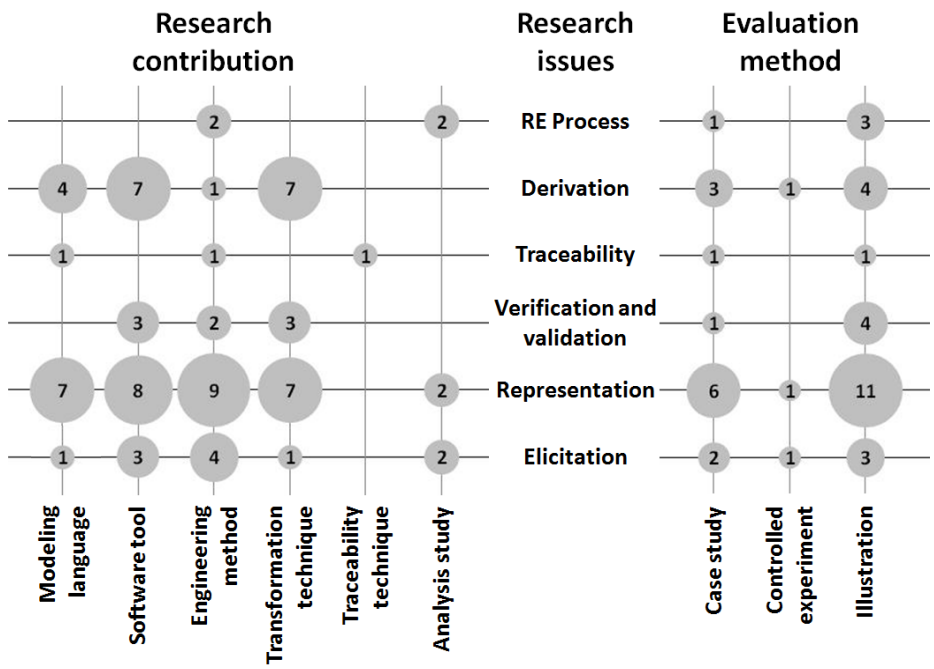

Fig. 2. Research issues distributed over research contributions and evaluation methods

From Fig. 1, we notice that a small portion of primary studies (8 out of 29) dealt with NFR while the majority dealt with functional requirements exclusively. Similarly, most of studies deal with requirements in *business or end-user applications*, with small portions dealing with *industrial* and *embedded systems*.

The detailed analysis for each primary study according to items in Table 1 is presented in Appendix 2. As mentioned above, multiple items can be checked for each paper. In order to have a synthetic and visual representation of these results, we display the data in a bubble diagram. Figure 1 displays the mapping of primary studies according to research contributions and research issues on one side (left), and evaluation method and research issues on the other side.

There is a number of remarks that can be made when looking at Fig. 2 and the detailed analysis in Appendix 2.

With no surprise, the RE research issue that is most tackled is *representation*. Authors propose new modeling languages, e.g. RDAL in (#02), AoUCM in (#07), (#14) and (#25), TADL2 in (#12), RSL in (#17), RSL-IL in (#11) and (#23), MoCKRE in (#26), SySML-sec in (#27). These languages are generally part of an engineering method and are supported by newly developed software tools. Accompanying methods and tools are seldom described with great details, the focus is on the modeling language per se. Some other authors, to deal with representation issues, do not propose new modeling languages but rely on existing ones: standard languages from the OMG family, e.g. UML in (#04), (#13), (#21) and (#22), BPMN in (#09), or non standard languages such as OpenUP process model in (#5), and goal oriented family of models, e.g. TROPOS in (#19) and KAOS in (#24).

The second topic that is most addressed is *derivation*. This is generally approached by using transformation techniques supported by software tools. Target languages can be in the UML family, e.g. sequence diagram in (#04) and use cases in (#9), or more specific, RAM in (#07) and (#14), RSL-IL in (#11), or even natural language in (#15).

However, transformation techniques can be leveraged for other purposes than derivation: in (#18) and (#21), transformations to formal notation (Petri nets, algebraic notation) are used for validation purpose. In (#01), validation is approached by transforming natural language (NL) requirements into intermediate representations from which a prototype is derived and that is used to communicate with end-user. A part from these three studies, requirements verification and validation issues are in fact insufficiently tackled. Traceability also is poorly tackled, only two studies deal with this issue: in (#16), an engineering method based on information retrieval technique is proposed to face the traceability issue in NL requirements, and in (#02), traceability links are incorporated in the RDAL modeling language.

Looking at requirement *elicitation*, it is generally handled as a side effect of facing a representation issue and introducing a new modeling language, e.g, (#26), or defining an engineering method, e.g. (#25) and (#29). In fact, study (#28) is the only one that tackles explicitly the elicitation problem. It proposes to use classification trees to capture requirements.

Beyond contributions in form of new artifact development, research can gain significant advancement from comparative and evaluation studies [8]. Only four papers presented at MoDRE workshops have contributions of this type. In (#08), the authors review available techniques for goal-oriented requirement modeling to face the problem of regulation conformance in the nuclear industry. In (#10), the author report lesson learnt from using models in RE. In (#13), the authors study the process of building requirement models and what can

impact its quality. And in (#19), a comparative study in relation with the representation issue, is conducted for goal-oriented models KAOS and NFR.

Finally, we looked at the number of citations, according to Google Scholar, each paper published in MoDRE has gained. Although the time span is limited to three years, the obtained numbers can give a preliminary idea about the popularity of certain research papers, and eventually, the category of research published at MoDRE workshop that attracts most attention. As citations counting in Google Scholar is not very rigorous, we manually checked all citations and filtered auto-citations, duplicates and incoherent references. These numbers are reported in columns C^1 and C^2 respectively in Appendix 1. The top 3 in terms of citations are the following studies:

- Paper (#08), 6 citations: an analysis study concerning available techniques for goal-oriented requirements modeling to face the problem of regulation conformance in the nuclear industry.
- Paper (#02), 4 citations: in this paper, inspired by SySML, the authors propose RDAL, a new requirement modeling language for critical embedded systems design that is better suited for handling traceability links.
- Paper (#05), 4 citations: the proposition of a complete engineering method that integrates MDE and RE including a precisely defined engineering process using the OpenUP process model.

It is difficult to infer significant insights from this limited set of cited papers. We can however hypothesize that they are pointers to hot topics in MoDRE, i.e. (i) RE for regulation conformance in complex systems, (ii) languages for requirements modeling and traceability in embedded systems, and (iii) precise definitions of engineering methods that combine RE and MDE.

To finish, and in light of the analysis we have previously made, we consider that the following research issues need to be further investigated:

- The derivation of system requirements and specifications out of goal-oriented models.
- The usage of MDE techniques for requirements verification and validation purpose.
- The usage of MDE techniques for requirement elicitation tasks.
- At the theoretical and terminological level, there is a need to clarify if CIM level in MDE can/should be positioned in the *problem* or in the *solution* space.
- To express complex transformations on requirements specific models, e.g. goal models, are existing transformation languages, i.e QVT and ATL, adequate for this purpose?
- To enhance knowledge accumulation, there is a need for more analysis studies that critically evaluate and compare existing approaches for MoDRE.
- Last but not least, there is a patent need for more empirical evidence about MoDRE through real-world case studies and laboratory experiments.

IV. Concluding Remarks

In this position paper, we have attempted to assess the knowledge that has been accumulated in three years of MoDRE workshop series. By systematically reviewing all published papers, we have classified research endeavors according to multiple dimensions. Analyzing the set of primary studies published along three years, and beyond the heterogeneity of problems addressed and solutions proposed, certain trends could be detected. We complemented this analysis by looking at most cited papers, and we hypothesized a set of research issues that need further investigations.

For future work, we think extending this study to a larger set of publications and build a full systematic review of MDE contributions to RE research.

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APPENDIX 1: LIST OF PRIMARY STUDIES PUBLISHED IN MODRE WORKSHOPS SERIES

Author (alphabetical order), title, page number	C[1]	C[2]
MoDRE 2011, August 29, 2011, Trento, Italy.		
(#01) D. Aceituna, H. Do, S.-W. Lee, "Interactive requirements validation for reactive systems through virtual requirements prototype", p. 1–10.	+3	+1
(#02) D. Blouin, E. Senn, S. Turki, "Defining an annex language to the architecture analysis and design language for requirements engineering activities support", p. 11–20.	+4	**+4**
(#03) J.-P. Corriveau, S. Bashardoust, V. D. Radonjic, "Requirements verification in the presence of variability", p. 74–78.	0	0
(#04) M. Goulao, A. Moreira, J. Araujo, J. P. Santos, "Streamlining scenario modeling with Model-Driven Development: A case study", p. 55-63.	+4	+3
(#05) G. Loniewski, A. Armesto, E. Insfran, "An architecture-oriented model-driven requirements engineering approach", p. 31–38.	+5	**+4**
(#06) J. Marincic, A. Mader, R. Wieringa, "Validation of embedded system verification models", p. 48–54.	+1	0
(#07) G. Mussbacher, J. Kienzle, D. Amyot, "Transformation of aspect-oriented requirements specifications for reactive systems into aspect-oriented design specifications", p. 39–47.	+6	+3
(#08) N. Sannier, B. Baudry, T. Nguyen, "Formalizing standards and regulations variability in longlife projects. A challenge for Model-driven engineering", p. 64–73.	+12	**+6**
(#09) F. L. Siqueira, P. S. M. Silva, "Transforming an enterprise model into a use case model using existing heuristics", p. 21–30.	+4	+2
MoDRE 2012, September 24, 2012, Chicago, Illinois, USA.		
(#10) B. Berenbach, "A 25 year retrospective on model-driven requirements engineering", p. 87–91.	0	0
(#11) D. Ferreira, A. R. da Silva, "RSLingo: An information extraction approach toward formal requirements specifications", p. 39–48.	+7	+1
(#12) A. Goknil, M. Peraldi-Frati, "A DSL for specifying timing requirements", p. 49–57.	0	0
(#13) C. Jeanneret, M. Glinz, B. Baudry, B. Combemale, "Impact of footprinting on model quality: An experimental evaluation", p. 77–86.	0	0
(#14) S. Leblanc, G. Mussbacher, J. Kienzle, D. Amyot, "Narrowing the gaps in Concern-Driven Development", p. 19–28.	+1	0
(#15) C. L. Robinson-Mallett, "An approach on integrating models and textual specifications", p. 92–96.	+1	+1
(#16) N. Sannier, B. Baudry, "Toward multilevel textual requirements traceability using model-driven engineering and information retrieval", p. 29–38.	+4	+1
(#17) M. Smialek, W. Nowakowski, N. Jarzebowski, A. Ambroziewicz, "From use cases and their relationships to code", p. 9–18.	0	0
(#18) E. Syriani, H. Ergin, "Operational semantics of UML activity diagram: An application in project management", p. 1–8.	+1	0
(#19) A. Teka, N. Condori-Fernandez, I. Kurtev, D. Quartel, W. Engelsman, "Change impact analysis of indirect goal relations: Comparison of NFR and TROPOS approaches based on industrial case study", p. 58–67.	+1	+1
(#20) R. Torres, N. Bencomo, H. Astudillo, "Mitigating the obsolescence of quality specifications models in service-based systems", p. 68–76.	+7	+3
MoDRE 2011, July 15, 2013, Rio de Janerio, Brazil.		
(#21) M. Borek, N. Moebius, K. Stenzel, W. Reif, "Security requirements formalized with OCL in a model-driven approach", p. 65–73.	0	0
(#22) U. Fatima, R. Braek, "Modelling multiplicity in choreography models", p. 74–78.	0	0
(#23) D. Ferreira, A. Rodrigues da Silva, "RSL-IL: An interlingua for formally documenting requirements", p. 40–49.	+2	0
(#24) J. C. Nwokeji, T. Clark, et B. S. Barn, "Towards a comprehensive Meta-Model for KAOS", p. 30–39.	0	0
(#25) A. Pourshahid, G. Mussbacher, D. Amyot, M. Weiss, "Requirements for a modeling language to specify and match business process improvement patterns", p. 10–19.	+1	+1
(#26) J. M. Rivero, E. Robles Luna, J. Grigera, G. Rossi, "Improving user involvement through a model-driven requirements approach", p. 20–29.	0	0
(#27) Y. Roudier, M. S. Idrees, L. Apvrille, "Towards the model-driven engineering of security requirements for embedded systems", p. 55–64.	+4	0
(#28) S. Sen, J. L. de la Vara, A. Gotlieb, A. Sarkar, "Modelling data interaction requirements: A position paper", p. 50–54.	0	0
(#29) F. Wanderley, J. Araujo, "Generating goal-oriented models from creative requirements using model driven engineering", p. 1–9.	+1	0

[1] Number of citations according to *GoogleScholar* on July 17th, 2014.

[2] Number of citations after filtering auto-citations, duplicates and irrelevance.

APPENDIX 2: DETAILED ANALYSIS OF PRIMARY STUDIES

	Research issue						Research contribution						Evaluation method		
Paper n°	Elicitation	Representation	Verif. and valid.	Traceability	Derivation	RE process	Modeling lang.	Software tool	Eng. method	Transf. technique	Traceability tech.	Analysis study	Case study	Experiment	Illustration
#01			x					x		x					x
#02		x		x			x								x
#03			x						x						x
#04		x			x			x		x			x		
#05		x				x			x						x
#06			x			x			x				x		
#07		x			x		x	x		x					x
#08		x				x						x			x
#09		x			x			x		x					x
#10	x					x						x			x
#11		x			x		x		x	x					x
#12		x					x						x		
#13	x											x		x	
#14					x		x	x		x					x
#15		x			x			x		x			x		
#16				x					x		x		x		
#17					x		x	x		x				x	
#18		x	x					x		x					x
#19		x										x		x	
#20					x			x					x		
#21			x					x		x					x
#22		x							x						x
#23		x					x		x				x		
#24		x						x	x						x
#25	x	x							x						x
#26	x	x					x	x	x						x
#27		x					x		x				x		
#28	x							x	x				x		
#29	x	x						x	x	x			x		