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Applying system dynamics approach in software and information system projects: A mapping study

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Context: Software and information system are everywhere and the projects involving them are becoming more complex. However, these projects performance patterns are not showing improvement or convergence over time. Additionally, there is a growing interest in modeling the complexities involved in such projects for evaluating long-term impacts, especially the dynamic dimension.
Objective: This study aims to analyze how the system dynamics approach has been used in the scientific literature to model complexity in software and information system projects.
Method: The research approach used was a mapping study that combined bibliometrics and content analysis to draw the scenario of the research literature related to software and information system projects, identifying patterns, evolution trends, and research gaps.
Results: The results show the focus of the studies analyzed regarding the step of policy design and evaluation in the modeling process (46%), besides investigating software development projects (34%). This study also reveals that the most employed tools are simulations (78%) and the causal loop diagram (61%), but only 37% presented model equations. As for the software and information system projects success dimension, system quality has prevailed (73%).
Conclusion: The mapping showed that there is a gap of studies exploring the implementation and post implementation phases of software and information systems. Few studies explored the social components; the majority of the studies focused on technical aspects and did not report the complete steps of system dynamics modeling development process. This lack of information hinders the reproduction of past results for expanding and developing new studies.

1. Introduction

Even with the progress obtained in the project management area in recent decades, the improvement in the project success rate has not been significant [81]. Following this trend, software and information system projects have also shown no convergence of performance patterns over time [44,45,62].

There are challenges reported in software and information system projects in various contexts, covering complex information systems deployment such as Enterprise Resource Planning (ERP) [58], international software development [15], military IT projects [105], and the British government initiative to automate healthcare records that extended from 2000 to 2010 and was abandoned after costs reached the order of 5 to 10 billion dollars [116]. As a consequence, there is an increasing trend of research on complex projects [24,61] and the dynamic aspect stands out among the dimensions that characterize complexity [56].

Sterman [[120], p. 11] defines dynamic complexity as the “often counterintuitive behavior of complex systems that arises from the interaction of the agents over time.” Dynamic complexity arises because complex systems are constantly changing, tightly coupled, governed by feedback, nonlinear, self-organizing, adaptive, and policy resistant among other characteristics.

In project management literature, managing complexity is becoming an important issue because "complexity has become an inseparable aspect of systems" [19], and the complexity of projects appears to be increasing [78], which requires the application of critical thinking [91]. System dynamics is particularly suited for modeling and analyzing the complexity, because it is “a perspective and set of conceptual tools that enable us to understand the structure and dynamics of complex systems. System dynamics is also a rigorous modeling method that enables us to build formal

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computer simulations of complex systems and use them to design more effective policies and organizations" [119].

There is an understanding that software and information system projects are broader than just placing artifacts in operation. Their introduction alters the structure and culture of an organization; in addition, they change the way people think and work [85]. Defining success of those initiatives is also a non-trivial activity, and consequently, there is no consensus in the research community about how to define and measure it [31,111].

It is not surprising that currently the software inventory owned by a company usually represents a significant share of its assets [127]; thus they have a vital interest in preserving and maximizing the investments made to build their software libraries and to optimize future ones.

The demand for better results increased in the last years due to the growing pressure for faster deliveries, lower costs, scope flexibility, system interconnectivity and business dependence on information systems for operating daily activities. These demands require changes in software development processes and in the organizations adopting those systems, which require significant investment and are complex to evaluate. How is it possible to understand and to anticipate the impacts these changes present? "Software Process Simulation and Modeling" (SPSM) is one area of research that has sought to address this issue and has brought contributions to better evaluate scenarios and to predict potential impacts of proposed software process improvements [64,106].

Regarding the approaches applied in research related to modeling, simulating and conducting experimentation, system dynamics is the most commonly used simulation approach employed for better understanding problems and proposing new theories when compared to Discrete Event, Agent Based, Monte Carlo among others [17,130]. This approach was formulated in the 1950s [51] and has been gaining attention in several scientific areas since.

In spite of this prevalence, there are still few publications presenting the application of the system dynamics approach in the context of software and information system projects. In general, literature reviews of this area assess the use of simulation independently of the approach adopted [17,64,130]. On the other hand, literature reviews regarding the system dynamics approach are not specific to the software and information system projects context [72].

In this scenario, the present work aims at analyzing the publications exploring the use of the System Dynamic approach in software and information system projects, identifying the main authors, main studies, themes, patterns and evolution trends of the research field. This paper seeks to fill the identified gap by performing a mapping study for answering the following research questions: How did the literature on system dynamics applied to software and information system projects evolve over time? How has the system dynamics approach been used in research related to software and information system projects?

This work is organized in six sections. Section 2 presents the literature background on the core research constructs, particularly the use of the system dynamics approach to software and information system projects. Section 3 lists the research methods employed for collecting and processing the articles sample. Section 4 yields the results from bibliometrics and content analysis, followed by the discussions of the results in Section 5. Finally, Section 6 presents the conclusions, the limitations of the current work and suggestions for future research agenda.

2. Background

This section of the work offers an overview of the literature related to the evolution of the concept of project success and the application of system dynamics approach in software and information system projects.

2.1. Project success

The iron triangle composed of the dimensions of time, cost and quality [18], which was widely used as the evaluation criterion for project success (Berssaneti and Carvalho, 2015, Carvalho et al. 2016), has been discussed and expanded in recent years to incorporate reflections such as: success evaluation criteria may vary from project to project due to difference in size, complexity, and uniqueness [84]. The perception of success varies depending on the perspective of stakeholders and the moment of the project at which the evaluation was made [36]. It is necessary to distinguish success and failure of a project from the project management standpoint [109,129] in addition to considering the intangible aspects when evaluating success [26,76].

Other authors have analyzed the evolution of publications related to project success over the past decades and concluded that it consists of a multi-dimensional and inter-related construct [30,115]. Several authors suggest that it is a multidimensional construct that can includes project efficiency, impact on the team, impact on the customer, business and direct success, and preparation for the future [115] and, more recently, the environmental and social sustainability dimension [29,30,74]. In addition, the perception of success and the relative importance of the associated dimensions may vary according to the personality and to the nationality of the individuals involved, on top of the project and contract type [83]. Furthermore, there is a complex relationship between managerial, technical and behavioral aspects and their impact on success, which may be moderated by a set of variables such as industry, project type and country.

Due to the subject being multidisciplinary, several models have been proposed to assess and to measure project success. One of these studies is of particular interest, as it is focused on evaluating the success of initiatives involving information systems. It is also one of the most cited models in the area, having accumulated so far more than 2200 citations of its first version [39] and more than 1900 of its second revision [38], according to the *"Web of Science Core Collection*" database. This model offers a comprehensive user-centered approach to evaluate success consisting of six interdependent dimensions: information quality (desirable characteristics of the system outputs); system quality (desirable characteristics of an information system); service quality (quality of the service or support that system users receive); intention to use and use of the system (degree and manner in which staff and customers utilize the capabilities of an information system); user satisfaction (users' level of satisfaction with the information system); and benefits generated (extent to which the information system are contributing to the success of individuals, groups, or organizations).

Furthermore, we selected the DeLone and McLean [38], because their proposed success model represents a process and a causal representation of the six interrelated success dimensions. The focus on causal relationship is also one of the core elements of the system dynamics approach, which tries to explain complex behaviors from the interactions (feedbacks) among the components of the system [119]. A process model suggests that an information system is first created, containing a set of features and can be characterized as exhibiting various degrees of system and information quality. Next, users experience these features by using the system and are either satisfied or dissatisfied with it or its information output. Finally, the impact that each user experiences by interacting and working collectively results in organizational impacts. In contrast, a causal model evaluates the covariance of the success dimensions to determine the causal relationships among them. For example, a system with a higher quality evaluation is expected to lead to higher user satisfaction and more system usage, consequently leading to positive impacts on individual productivity, and organizational productivity improvements.

2.2. System dynamics in software and information system projects

The interest of researchers and practitioners in process modeling and simulating has grown. It has been perceived as an approach that can be used to help the analysis of complex business context, to support the design and evaluation of potential intervention policies, and to explore hypothetical scenarios that would often be economically unfeasible to explore in the real world. Although modeling and simulation techniques have been long and widely employed in a variety of disciplines, their adoption in the software development and process improvement areas occurred with significant delays [64].

There are several approaches for building models and performing simulations (Petri nets, agent-based, Monte Carlo, Bayesian networks etc.); however, a literature review exploring studies on the application of simulation in the software industry, published between 1998 and 2012, indicates that the predominant approach applied is system dynamics, corresponding to approximately 37% of the studies [17].

The system dynamics approach was developed in the 1950s, by Jay Forrester [51], to study complex business problems and was later expanded to study problems associated with the sustainability of population growth in urban centers and throughout the world [48,50]. In the mid-1980s, studies applying this approach to study the dynamics associated with software projects began to emerge [1,3]. Simulation models of software processes proliferated in the 1990s [2,64,67,123].

Research works related to software and information system projects deal with the development, management and effects of systems on people, organizations, and markets. These projects are socio-technical systems that involve interactions between technical components, people, data, and organizational issues. These interrelationships create a dynamically complex environment containing feedback loops, accumulations and delays between causes and effects, presenting behaviors which are often not trivial, thus requiring non intuitive solutions by making use of the system dynamics approach suitable for studying how these initiatives evolve over time [55].

3. Research design

A mapping study approach was applied by merging bibliometric [60] and content [41] analysis to identify the landscape of the scientific literature on the use of the system dynamics approach in researches related to software and information system projects, describing trends and key topics covered. These analyses are complementary, as the first tries to identify patterns of literature based on publication data and the second captures information to quantify sequences of words to model a related language used by different research fields [28].

3.1. Research questions

In order to achieve the proposed objective in this work, the research questions previously presented in section "1. Introduction", were deployed according to the structure shown in Table 1.

3.2. Sampling process

The "*Web of Science Core Collection*" database was used for collecting the publications sample and the workflow of the activities performed for this is shown in Fig. 1.

This database was selected because it provides an interface to simultaneously search across different sources using a common set of search fields for obtaining comprehensive results. It includes studies from 1985 to the current date, covering the Science Citation Index Expanded, Social Sciences Citation Index, Arts & Humanities Citation Index, and Emerging Sources Citation Index, which comprehends studies from ACM, EBSCOhost, Elsevier, Emerald, IEEE, INFORMS, ProQuest, SAGE, Springer, Taylor & Francis, Wiley, among many other publishers. This database is also the source for computing the "Journal Citation Report" index, which is one of the most used mechanisms for evaluating journals based on citation data.

For defining the search string, an iterative construction process was employed by performing an initial manual search combining the terms "system dynamics", "software" and "information system". The keywords for relevant papers already known were also evaluated along with synonyms and relevant keywords. This process was repeated with the resulting sample until no additional paper was found. Finally, Boolean operators were used to combine the terms into a single search string, presented in Table 2.

Only publications of type "Articles" were selected due to the rigor of their associated review process before being published; in addition, they also contain all of the necessary information for performing the bibliometric analysis, such as authors, references, the number of citations and publication year [28].

This search led to an initial sample of 284 articles, with years of publication ranging from 1986 to 2015. Afterwards, the titles and abstracts were analyzed in order to assess the compliance of the articles with the objective proposed herein (use of system dynamics approach in research works related to software and information system projects).

As suggested by Carvalho et al. [28], in the screening process, the authors of the current study read the title and abstracts of the 284 articles separately. Then, they only excluded from the sample the papers that all agreed did not meet the criteria for inclusion, which were the fit to the research scope of system dynamics and also relate to software and information system projects context. When the consensus was not achieved among authors, the full paper was analyzed and discussed (first screening depicted in Fig. 1). Next, the snowball sampling technique [47] was employed to identify the most relevant references that were not retrieved in the initial sample, considering the most cited studies that fit the research scope, using the same screening process (second screening depicted in Fig. 1). A final selected sample of 102 articles resulted from this process.

3.3. Data analysis

The research sample was analyzed in two steps: bibliometric analysis, and content analysis and coding. Fig. 2 shows the workflow of the activities conducted, adapted from Carvalho et al. [28], which is detailed in the following subsections.

3.4. Bibliometric analysis

The bibliometric analysis was applied to addresses research questions RQ1.1, RQ1.2, RQ1.3, and RQ1.5. It can be defined as a set of techniques to quantify the written communication process [60] and allows identifying the most productive authors, the journals and periods in which the publications occurred, the evolution of publications over time, the most influential articles in a particular set of studies, and the topics closely related to the subject of the research [93].

The software "Science of Science" (Sci2) tool version 1.1 [110] was used for constructing the paper citation and keywords co-occurrence networks. The Sci2 tool is a modular toolset for

Table 1
Deployment structure of the research questions.

RQs	Deployment
RQ1. How did the literature on system dynamics applied to software and information system projects evolve over time?	RQ1.1. What are the key journals for this topic and how does their number of publications evolve over time? RQ1.2. What are the most influential studies (considering the number of citations)? RQ1.3. What core references most influenced the identified studies (considering not only the primary studies contained in the selected sample but also their references)? RQ1.4 What are the characteristics, concerning the kind of study, research methods and the approach used by the selected studies? RQ1.5. What are the hot topics addressed by these studies?
RQ2. How has the system dynamics approach been used in researches related to software and information system projects?	RQ2.1. Up to which stage was the modeling process carried out? RQ2.2. What modeling tools were used? RQ2.3. What were their key points addressed (purposes)? RQ2.4. What were their organizational breadth and time span (scopes)? RQ2.5. What were the result variables concerning the project success dimensions explored?

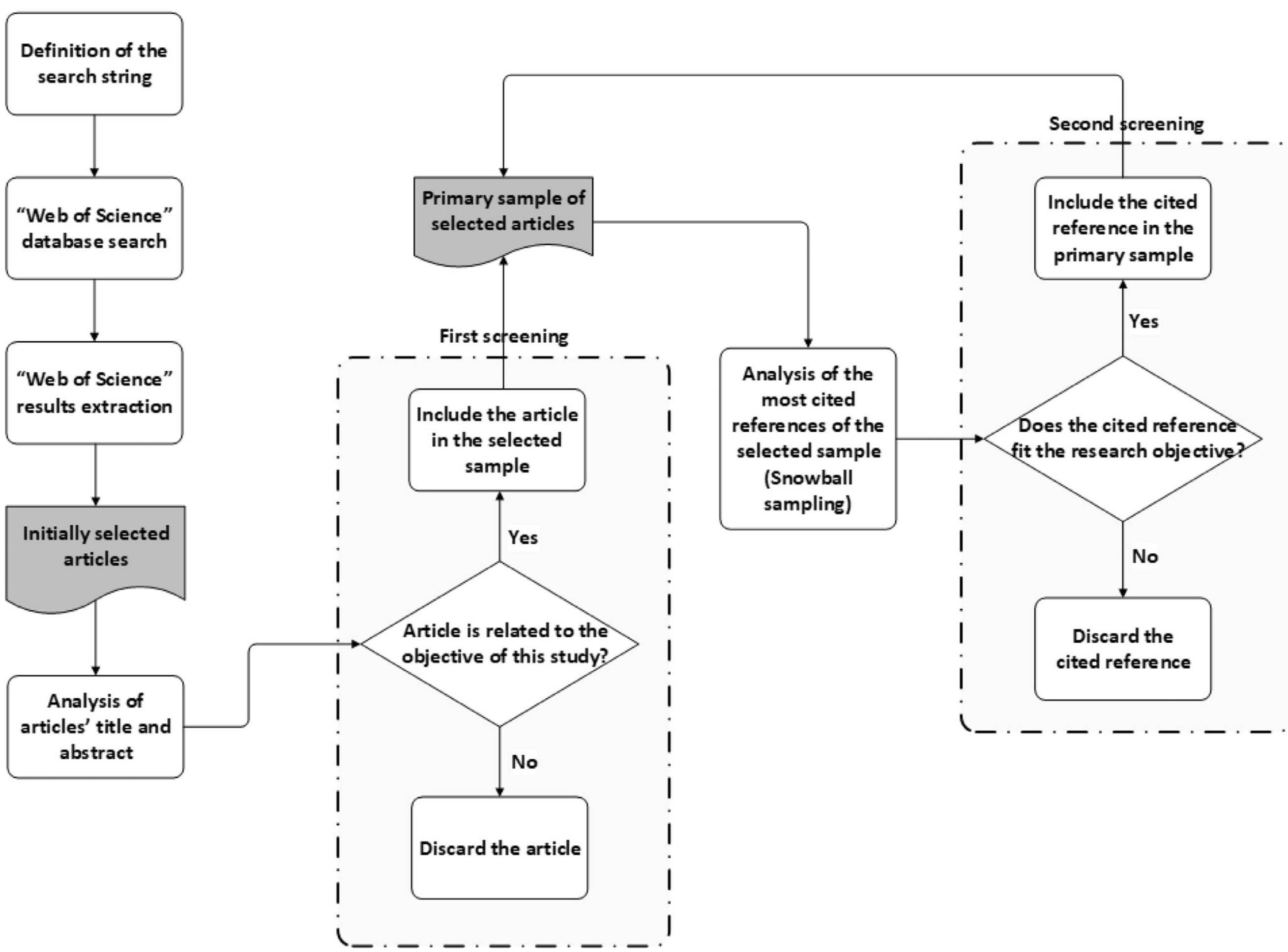

Fig. 1. Workflow performed for obtaining the sample of the publications selected.

Table 2
Combination of terms applied for searching publications from the "*Web of Science Core Collection*" database.

Terms used for database search	Number of results
(("system* dynamic*") AND (("software" AND "project management") OR "software development" OR "software engineer*" OR "software process" OR "information system*")) OR (("dynamic* model*") AND (("software" AND "project management") OR "software development" OR "software engineer*" OR "software process" OR "information system*"))	284

studying scientific communication, supporting the temporal, geospatial, topical and network analysis.

The dataset of the selected sample was exported from the "Web of Science" database as "Plain Text," imported into the Sci2 tool, and then the construction of networks followed the procedure proposed by Börner and Polley [23], detailed below.

- Paper citation network: the data was prepared using the "Extract Direct Network" processor, setting the "Source Column" to "Cited References" and the "Target Column" to "Cite Me As". The result was a direct network containing nodes representing both the 102 original studies, plus their references and citation links. Each node has two citation counters: the local citation

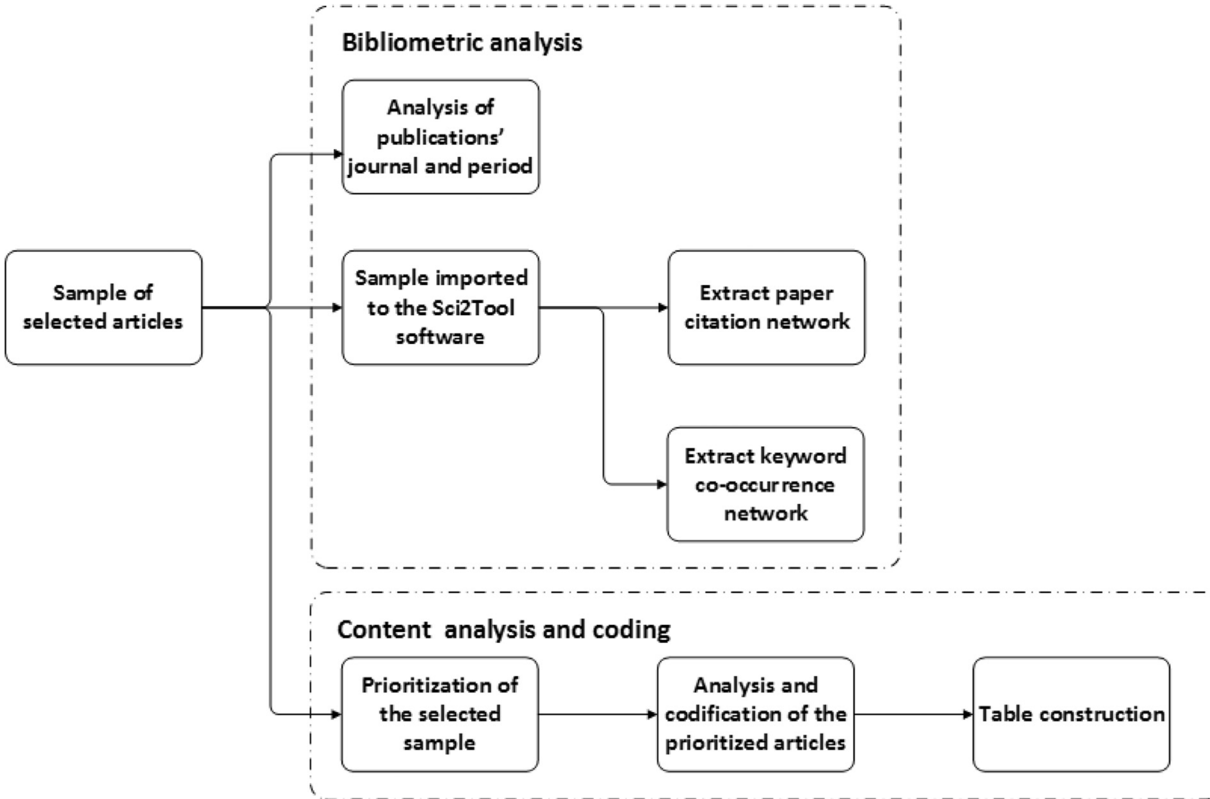

Fig. 2. Workflow conducted for analyzing the selected sample.

count (LCC), which indicates how often a paper is cited by papers in the dataset; and the global citation count (GCC), which equals the citation value of the "Web of Science" records.

- Keyword co-occurrence network: the data was first treated with the "Lowercase, Tokenize, Stem and Stopword Text" preprocessor, and then prepared using the "Extract Word Co-Occurrence Network" processor setting the "Node Identifier Column" to "Cite Me As" and selecting the "Original Keywords" as the search field. The result was a weighted and undirected network.

The cited references were analyzed for identifying the most influential studies. This analysis is based on the premise that authors cite publications they consider important for the development of their research; therefore, frequently cited documents are likely to have exerted a greater influence than those less frequently cited [97].

Afterwards, the publication period (1986–2015), which comprehends the period between the publication years of the oldest to the most recent articles, was divided into three equal consecutive sub-periods of 10 years: 1986–1995, 1996–2005, 2006–2015 and another analysis was performed for trying to identify changes of influences that may have occurred over time. If it were not possible to identify a change in the publications pattern using this initial setting, the period would eventually be divided into smaller sub-periods.

3.5. Content analysis and coding

The content analysis was applied to address research questions RQ1.4, RQ2.1, RQ2.2, RQ2.3, RQ2.4, and RQ2.5. This technique was adopted because it offers a flexibility for defining the coding scheme, which is then used in the frequency statistics of the codes and their relations, as well as the qualitative interpretation analysis [41].

For coding and performing the content analysis, the selected sample was organized by descending order according to the year of publication and number of references. Later, the articles published in journals with a 2015's impact factor (JIF) less than "1" and the studies published before 2005 with less than five citations were excluded (Fig. 3). This JCR threshold is related to the classification of the journal in the first and second quartile of the research area.

As the interest of this work is to assess the current impact that published studies have on other research publications, the criteria adopted consider the current impact factor for all articles. Consequently, recently articles published in journals with higher impact factor have an advantage over those published in journals with lower impact factor. However, the number of citation criteria permits that studies published more than ten years ago in journals that nowadays have an impact factor less than "1" to be included in the analysis, as over a decade they received more than five studies.

This selection resulted in 59 items, which were fully read and assigned the categories for each classification described below. Each paper could be classified in none, one or more than one category for each of the classification codes.

A coding scheme used by Carnevalli and Miguel [27] was adapted for coding the selected sample of articles shown in Table 3, which also identifies the research question addressed by each of the defined codes. As suggested by Carnevalli and Miguel [27], the affinity diagram was used to organize the articles in a hierarchical form, classifying them according to their kind of study, approach, application of the system dynamics approach (modeling process step and tools used), and stated objectives (purpose, scope, and success dimensions).

First, the initial two classifications proposed by Carnevalli and Miguel [27] were applied and the articles were organized into two groups according to the type of study: conceptual (theoretical-conceptual, modeling, literature review, and simula-

Table 3
Coding scheme used to classify selected studies.

C1 – Kind of study (RQ1.4)	**C5 – Purpose (RQ2.3)**
KS1 – Modeling	P1 – Training and learning
KS2 – Theoretical-conceptual	P2 – Understanding
KS3 – Literature review	P3 – Process improvement and technology adoption
KS4 – Simulation	P4 – Control and operational management
KS5 – Case study	P5 – Planning
KS6 – Action-research	P6 – Strategic management
KS7 – Experimental	
C2 – Approach (RQ1.4)	**C6 – Scope (RQ2.4)**
A1 – Quantitative	S1 – Portion of life cycle
A2 – Qualitative	S2 – Development project
C3 – Modeling process step (RQ2.1)	S3 – Multiple concurrent projects
MS1 – Problem articulation and formulation of dynamic hypothesis	S4 – Long-term product evolution
MS2 – Formulation of a simulation model	S5 – Long-term organization
MS3 – Tests	**C7 – Success dimensions (RQ2.5)**
MS4 – Policy design and evaluation	SD1 – Information quality
C4 – Tools (RQ2.2)	SD2 – System quality
T1 – Causal loop diagram	SD3 – Service quality
T2 – Stock and flow diagram	SD4 – Intention to use
T3 – Model equation	SD5 – User satisfaction
T4 – Simulation	SD6 – Net benefits

tion) or empirical (case study, experimental and action research). Then the articles were classified according to the nature of the data used in the study (quantitative and qualitative).

To assess the progress achieved by each of the articles analyzed in terms of the stages of the modeling process, the steps of the modeling process proposed by Sterman [119] were used, including: problem articulation and formulation of dynamic hypothesis; formulation of a simulation model; testing; and policy design and evaluation. Additionally, the modeling tools described by Sterman [120] and used in the studies were identified (casual loop diagram, stock and flow diagram, model equations and simulation).

For evaluating the purpose and scope, the articles were classified applying a coding scheme and the categories proposed by Kellner et al. [64]. Regarding the purpose dimension, the studies were then classified based on training and learning; understanding; process improvement and technology adoption; control and

Table 4
Journal and period of publication distributions.

Journal	P1 1986/1995	P2 1996/2005	Δ	P3 2006/2015	Δ	TOTAL	JIF (2015)
Journal of systems and software	3	14	↑	1	↓	18	1.424
System dynamics review	1	3	↑	4	↑	8	1.194
Information and software technology	0	3	↑	2	↓	5	1.569
Software quality journal	0	4	↑	1	↓	5	0.787
European journal of information systems	0	3	↑	1	↓	4	2.892
Int. journal of software eng. and knowledge eng.	0	4	↑	0	↓	4	0.240
Mis quarterly	1	2	↑	0	↓	3	5.384
Computers in human behavior	1	1	–	1	–	3	2.880
Lecture notes in computer science	0	3	↑	0	↓	3	N/A
Others	12	17	↑	20	↑	49	
Total	**18**	**54**	↑	**30**	↓	**102**	

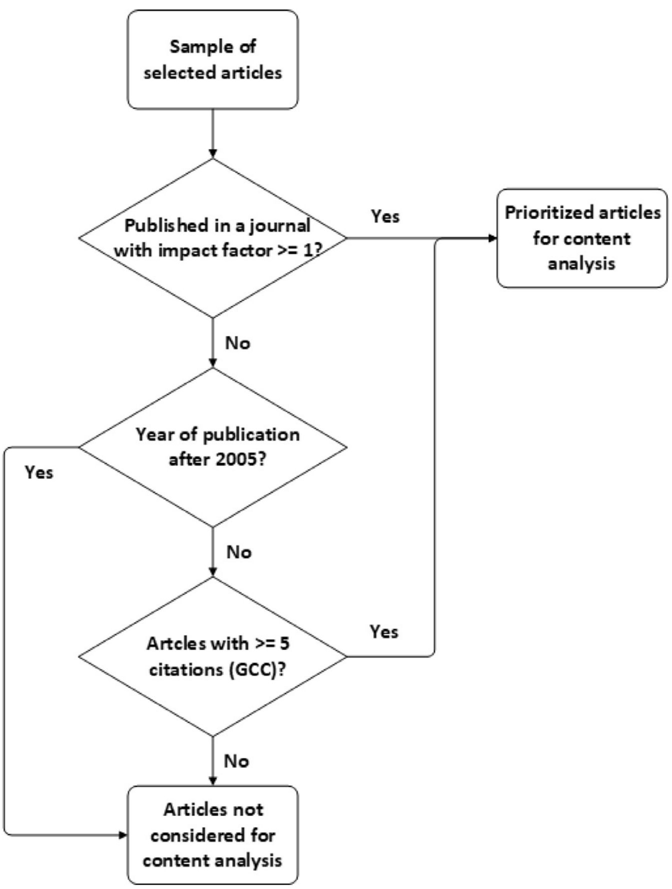

Fig. 3. Workflow performed for prioritizing the articles for the content analysis.

operational management; planning; and strategic management. Moreover, the studies were classified in relation to the scope of concern: part of the lifecycle; development project; multiple projects and competing; long-term evolution of products and services; and long-term organizations.

Finally, for evaluating the result variables addressed by the articles selected and related to the dimensions of Information System success proposed by DeLone and McLean [38] were also identified.

4. Results

The following subsections present the results from the bibliometric analysis, and the content analysis and coding.

4.1. Bibliometric analysis

The 102 selected articles were published in 48 different journals. Table 4 presents the number of publications per journal and sub-period (P1-1986–1995, P2-1996–2005, and P3-2006–2015). Only those journals presenting, at least, three publications between 1986 and 2015 are shown and the ones that had less than three publications are grouped in the row labeled “others”.

The bibliometric analysis reveals the inter-relationship between the articles under analysis. The first network built and analyzed was the paper citation between studies contained in the sample. The degree of the nodes was employed as the criteria for pruning the resulting network, which consists of the number of citations received for each work. The fifteen papers presenting the highest degree were selected and the isolated nodes were excluded. The result is shown in Fig. 4; the size of the nodes is the number of citations received by the papers within the selected sample (local citation count), and the value is indicated between brackets.

The second network used to analyze the selected sample was the keyword co-occurrence. The topics were clustered using the Affinity Diagram technique, by organizing the keywords under common themes defined by the authors, and after its construction, it was pruned to show the twenty most central words based on their betweenness centrality property, as shown in Fig. 5. The thickness of the link represents the frequency of the co-occurrence (proximity).

The keywords were grouped into four clusters according to the thematic group: 1) strategic objectives, 2) dependent variables, 3) software engineering and 4) modeling and simulation. Table 5 shows the betweenness centrality index of the nodes, which suggests terms with greater relation to the string used for searching the studies addressing the employment of the system dynamics approach in research of software and information system projects.

To identify the most influential studies on system dynamics applied to software and information system projects, that comprehends not only the selected sample extracted from the database and analyzed in the first screening but also their most relevant references, which include any kind of publication (articles, books, thesis etc.), gathered through snowball sampling and analyzed in the second screening (see Fig. 1), and to evaluate how their influence changed over time, the number of citations received by each reference (local citation count) was calculated using the “Paper citation network” for each sub-period and the scenario is depicted in Table 6. The column “Quant.” depicts the number of citations received by each reference, and the “%” column presents the relative value of the number of citations received by the number of studies published in the period (“*n*”), showing the percentage of studies from that period that cited each reference.

The information contained in Table 6 is also graphically shown in Fig. 6 to facilitate the identification of the main variations

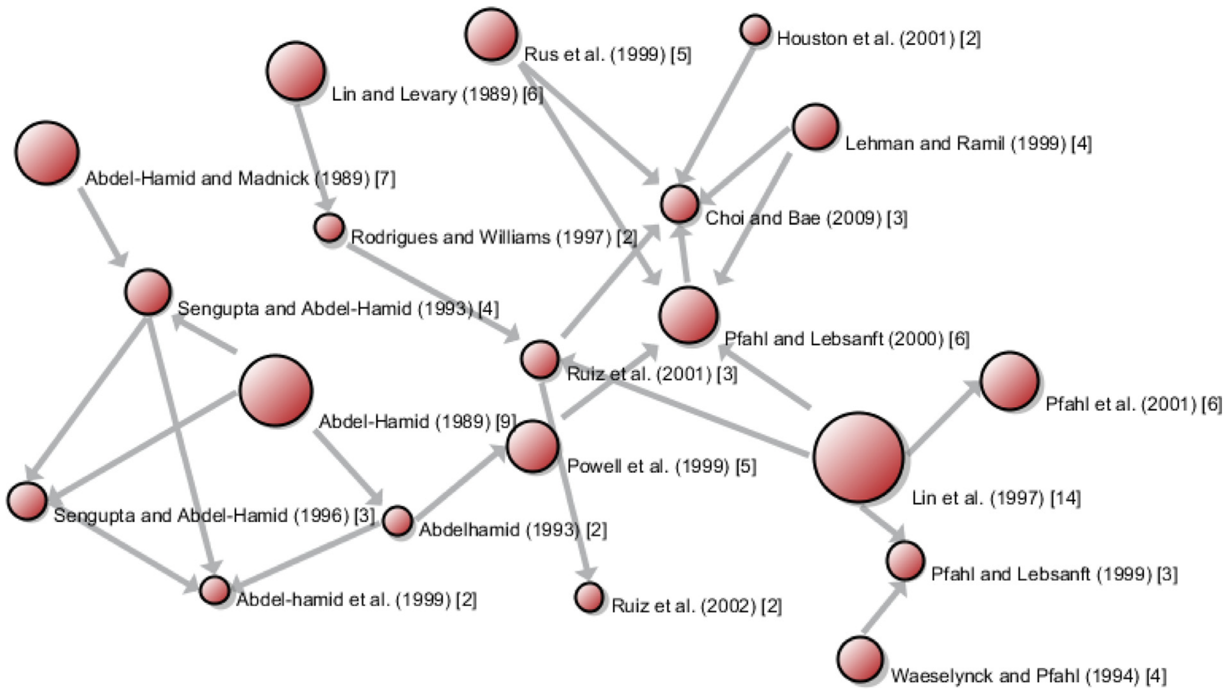

Fig. 4. Paper citation network.

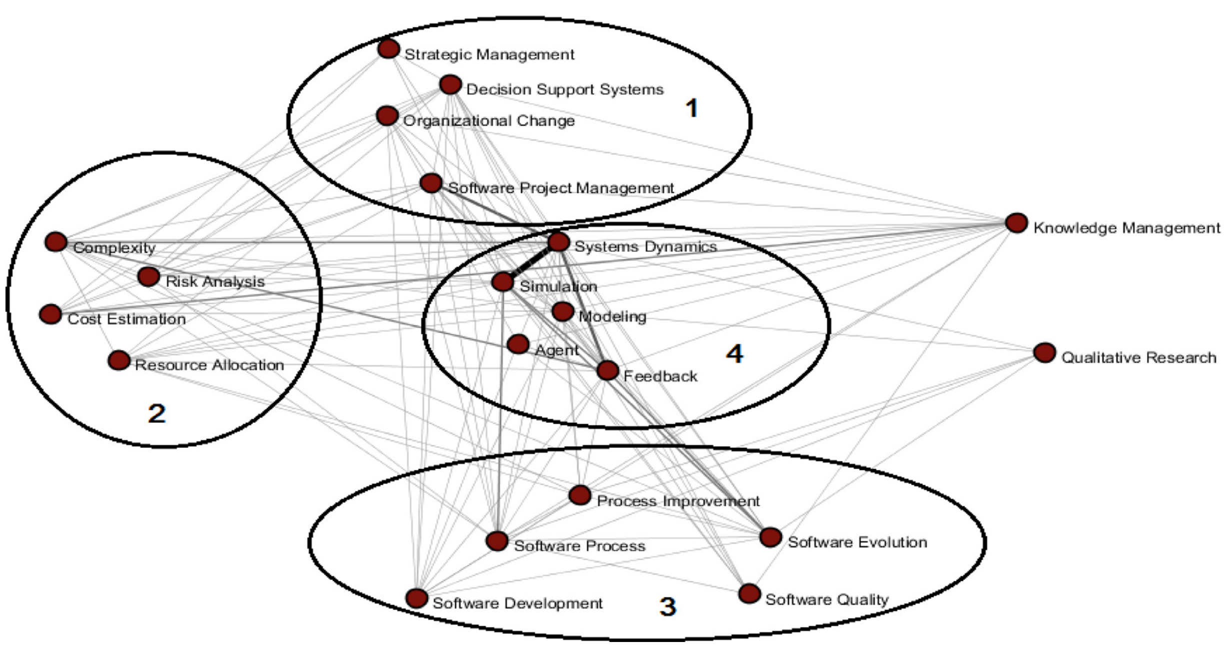

Fig. 5. Keywords co-occurrence network.

Table 5
Betweenness centrality of the keywords network.

Keywords	Betweenness centrality	Keywords	Betweenness centrality
Systems dynamics	3057.73	*Organizational change*	290.54
Modeling	2400.31	*Resource allocation*	237.99
Simulation	1684.06	*Cost estimation*	227.81
Decision support systems	1376.23	*Software quality*	219.79
Knowledge management	1239.75	*Complexity*	195.72
Software project management	859.96	*Process improvement*	163.74
Software process	790.72	*Risk analysis*	151.27
Software development	699.77	*Qualitative research*	89.40
Software evolution	652.13	*Strategic management*	78.89
Feedback	629.97	*Agent*	72.35

Table 6
Raw and relative citation frequency.

Publication	Total (1986–2015) n = 102		P1 1986–1995 n = 18		P2 1996–2005 n = 54		P3 2006–2015 n = 30	
	Quant.	%	Quant.	%	Quant.	%	Quant.	%
Abdel-Hamid and Madnick [2]	43	42.2	3	16.7	27	49.1	13	44.8
Boehm [21]	37	36.3	16	88.9	19	34.5	2	6.9
Forrester [51]	35	34.3	14	77.8	15	27.3	6	20.7
Richardson and Pugh [99]	26	25.5	6	33.3	16	29.1	4	13.8
Kellner et al. [64]	16	15.7	0	0.0	11	20.0	5	17.2
DeMarco [40]	16	15.7	12	66.7	3	5.5	1	3.4
Lin et al. [67]	14	13.7	0	0.0	11	20.0	3	10.3
Brooks [25]	14	13.7	10	71.4	3	5.5	1	3.4
Sterman [119]	12	11.8	0	0.0	3	5.5	9	31.0
Abdel-Hamid [7]	9	8.8	3	16.7	1	1.8	5	17.2
Abdel-Hamid [1]	9	8.8	8	44.4	0	0.0	1	3.4
Forrester [49]	8	7.8	1	5.6	7	12.7	0	0.0
Madachy [73]	8	7.8	0	0.0	7	12.7	1	3.4
Forrester and Senge [52]	7	6.9	0	0.0	6	10.9	1	3.4
Lyneis and Ford [72]	7	6.9	0	0.0	0	0.0	7	24.1
Abdel-Hamid and Madnick [10]	7	6.9	2	11.1	0	0.0	5	17.2
Roberts [100]	7	6.9	2	11.1	4	7.3	1	3.4
Tvedt [121]	7	6.9	0	0.0	6	10.9	1	3.4
Morecroft [82]	7	6.9	1	5.6	6	10.9	0	0.0
Graham et al. [57]	7	6.9	1	5.6	5	9.1	1	3.4

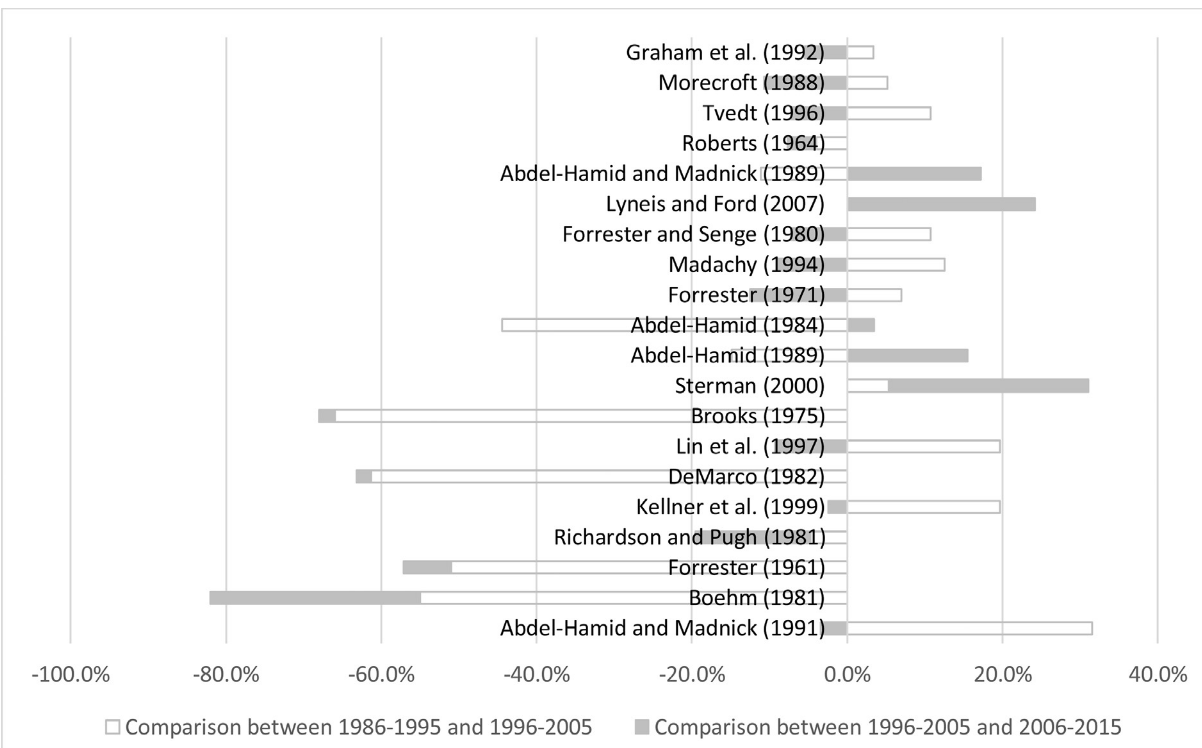

Fig. 6. Changes in influence of general references citation.

of influences and trends over time. The white bars show the corresponding percentage gain or loss of influence from the first sub-period (1986–1995) to the second (1996–2005), and the gray bars show the changes from the second sub-period (1996–2005) to the third (2006–2015).

4.2. Content analysis and coding

Table 7 exhibits a statistical summary of the result of the codification of the 59 studies, selected according to the criteria described in section “3.5” and using the coding scheme shown in Table 3. The complete results are available in “Appendix A” of this work. The relative amount (column “% Relative”) was calculated based on the number of articles assigned to each category (column “Occurrences”) and the number selected for codification (59) to identify the code frequency.

5. Discussion

The following subsections discuss how the results presented in the previous section (“4 Results”) address the research questions (RQs) formulated in section “3.1 Research questions”.

Table 7
Main results of the content analysis and coding.

Coding classification		Occurrences	% Relative
C1 – Kind of study	KS1 – Modeling	22	37
	KS2 – Theoretical-conceptual	5	8
	KS3 – Literature review	2	3
	KS4 – Simulation	21	36
	KS5 – Case study	29	49
	KS6 – Action-research	2	3
	KS7 – Experimental	13	22
C2 – Approach	A1 – Quantitative	32	54
	A2 – Qualitative	27	46
C3 – Modeling process step	MS1 – Problem articulation and dynamic hypotheses formulation	6	10
	MS2 – Formulation of a simulation model	2	3
	MS3 - Tests	19	32
	MS4 – Policy design and evaluation	27	46
C4 – Tools	T1 – Causal loop diagram	36	61
	T2 – Stock and flow diagram	21	36
	T3 – Model equation	22	37
	T4 – Simulation	46	78
C5 – Purpose	P1 – Training and learning	10	17
	P2 – Understanding	16	27
	P3 – Process improvement and technology adoption	13	22
	P4 – Control and operational management	11	19
	P5 – Planning	15	25
	P6 – Strategic management	12	20
C6 – Scope	S1 – Portion of life cycle	18	31
	S2 – Development project	20	34
	S3 – Multiple concurrent projects	5	8
	S4 – Long-term product evolution	10	17
	S5 – Long-term organization	8	14
C7 – Success dimension	SD1 – Information quality	0	0
	SD2 – System quality	43	73
	SD3 – Service quality	5	8
	SD4 – Intention to use	14	24
	SD5 – User satisfaction	18	31
	SD6 – Net benefits	9	15

5.1. How did the literature on system dynamics applied to software and information system projects evolve over time? (RQ1)

This research question is addressed with the following discussion related to the sub questions RQ1.1, RQ1.2, RQ1.3, RQ1.4, and RQ1.5.

5.1.1. What are the key journals for this topic and how does their number of publications evolve over time? (RQ1.1)

According to Table 4, approximately 44% of the papers were published in six different journals, which published, at least, four articles. The journals are *Journal of Systems and Software, System Dynamics Review, Software Quality Journal, European Journal of Information Systems, Information and Software Technology,* and *International Journal of Software Engineering and Knowledge Engineering*. The *Journal of Systems and Software* was the one that concentrated most of the published works during P1 (1986–1995) and P2 (1996–2005). However, during the last analyzed period P3 (2006–2015), the journals *System Dynamics Review* and *Information and Software Technology* can be seen as the key journals that recently published works on the topic.

It is possible to identify a concentration of publications in journals related to the field of software, systems, technology and management of information systems. The only exception is *System Dynamics Review*, which is focused on the application of the system dynamics approach to explore social, technical, managerial and environmental issues. A significant growth of publications in the P2 period (1996–2005) can also be noted compared to P1 (1986–1995), possibly due to the publication of studies of great influence during this period [2,119]. On the other hand, the analysis showed a strong decline of almost 45% for the P3 period (2006–2015), in relation to P2 (1996–2005), which is intriguing since in (P3) the complexity theme in the context of projects presented a growing interest [24,61]. Project complexity is a property influenced by project size, variety, interdependence and context which makes it difficult to understand, foresee, and keep under control its overall behavior, even when given reasonable complete information about it [122].

5.1.2. What are the most influential studies (considering the number of citations)? (RQ1.2)

From the analysis of Fig. 4, it is possible to identify the six most cited studies in other publications contained in the sample, which forms the set of the most influential studies in the area of the period analyzed, from 1986 to 2015. In the following paragraphs, these studies are briefly described in order of relevance.

In the first position is a work with fourteen citations by Lin, Abdel-Hamid and Sherif [67] presenting a simulation model of the software development process used by NASA and which was designed to serve as a planning tool for examining the trade-off relationships between cost, schedule, scope and their implications on the outcome of the project when different management policies are employed.

The second publication corresponds to the work by Abdel-Hamid [7], with nine citations, which explores the dynamics of human resources allocation throughout the lifecycle of software development projects. In the paper, the author proposes a simulation model to conduct experiments for studying and predicting the effects of allocation policies on the project behavior.

Next is the work by Abdel-Hamid and Madnick [10], with seven citations, consisting of a reflection on the paradigm of the software industry in which, despite the progress achieved on the processing power, hardware costs, along with applications of scientific and engineering rigor for the development process, little attention was given to the managerial aspects. The paper discusses how the system dynamics approach can assist the studying and predicting the dynamics implication of managerial policies and procedures on the software development process in various areas.

Finally, three papers received six citations each. One presents the application of a tool in order to assist managers in reducing the uncertainties associated with cost, time and resources during the planning, management and control phases for medium and large software development projects [68]. The second addresses the use of a simulation model to analyze the impact of the requirements volatility in project performance [89]. The last one presents the concept of a computer-based training module for student education in software project management implemented applying the system dynamics approach [86].

5.1.3. What core references most influenced the identified studies (considering not only the primary studies from the selected primary sample but also and their references)? (RQ1.3)

From the analysis of Table 6 and Fig. 6, it was identified that the studies with greater reduction in the number of citations over time correspond to theoretical frameworks in the fields of software engineering [21,25,40] and system dynamics [51]. These studies were published before the period covered by this study (before 1986) and showed a reduction of more than 50% in their citation frequency over the period comprehended from 1986 to 2015.

As the literature on system dynamics and its application to software and information system projects developed and grew, these seminal references became less cited. Consequently, studies that presented a higher citation growth (above 20%) were published in the period P2 (1996–2005) and correspond to the further development of the field of system dynamics [119] and the application of its approach in project management contexts [71]. Regarding the studies maintaining relevance since the second period (P2), it was noted just one work which represents a proposal of a scientific model of software projects management process [2].

5.1.4. What are the characteristics, concerning the kind of study, research methods and the approach used by the selected studies? (RQ1.4)

Based on the information in Table 7, it is possible to identify a predominance of studies that build models from case studies and conduct simulations in order to evaluate scenarios and hypotheses (“C1 – Kind of study”).

Regarding the approach adopted (“C2 – Approach”), there was a balance between qualitative and quantitative studies. This finding may be justified by the fact that many studies used qualitative analysis for the construction of models and produce quantitative data from the simulation models [59,67,124].

5.1.5. What are the hot topics addressed by these studies? (RQ1.5)

The central keywords presented in Fig. 5 support and corroborate the coding scheme selected for conducting the content analysis of the articles, where the “C1 – Kind of study” and the “C3 – Modeling process step” codes can be identified by the term “modeling”, “simulation” and “feedback”. The code “C5 – Purpose” of the studies are related to the terms “knowledge management”, “support systems for decision making”, “organizational changes”, “improvement process” and “strategic management”.

It is also possible to note the presence of a set of variables that are evaluated during the planning phase and throughout the project lifecycle such as “resource allocation”, “cost estimate”, “quality of software”, “complexity” and “risk analysis”.

5.2. How has the system dynamics approach been used in researches related to software and information system projects? (RQ2)

Based on the results obtained by the content analysis and the codification of the selected articles (see Table 7), it was observed that a significant part of the studies (46%) reached the policy design and evaluation step in the modeling process (RQ2.1).

Regarding the RQ2.2, it was possible to identify that most of the studies used simulation tools (78%) [63,65,106] and presented causal loop diagrams (61%) [16,35].

This number is slightly greater than the number of studies that applied tools such as stock and flow diagrams (36%) or model equations (37%). One explanation for this phenomenon is that a significant portion of the work uses the model proposed by Abdel-Hamid and Madnick [2] as a starting point for their research [46,107,125,126].

This finding is similar to the scenario depicted by Rahmandad and Sterman [95] where they found that only 41% of the studies they analyzed include model equations, comparing to 37% identified by the current work.

According to their purpose (RQ2.3 and “C5 – Purpose”), most of the studies were intended to broaden the understanding of the problems under study (27%), serve as a support tool for the planning activity (25%), process improvement (22%), and strategic planning (20%).

The focus of the studies (RQ2.4 and “C6 – Scope”) is to analyze software development project (34%) and parts of the project cycle (31%), a small portion of the work evaluates long-term developments of products (17%), long-term organizations (14%), and multiple projects effects (8%).

Regarding the success dimensions addressed (RQ2.5 and C7 – Success Dimension), it was noted a concentration of studies exploring the dimension of system quality (73%), which mainly represent the initial phases of the construction and implementation of the software and information systems, primarily related to criteria such as time, cost and scope. Likewise, since 2005, there is an increase in the number of studies addressing the success dimensions of user satisfaction (31%) and the intention to use the system (24%).

5.3. Threats to validity

Among the main constraints to be pointed out is the need for future studies to empirically validate and reproduce the results presented in this mapping study, which combined the bibliometric and the content analysis. Moreover, the use of the “Web of Science” database as the only source for extracting the selected sample, the search string design, and the adopted criteria for papers selection and prioritization of the selected sample, could eventually have excluded some studies from the analysis. However, this omission may have been reduced as this study evaluated not only the primary studies from the selected sample but also its references list and any inconsistency should be identified.

The subjectivity associated with the criteria used for classifying the prioritized studies according to the coding scheme proposed for content analysis was mitigated by the extraction and categorization process adopted. Two of the authors of this study independently read and categorized each of the studies. Then, the third author was responsible for compiling the categorization results and for resolving any kind of divergence and inconsistency between the analyses of the first two authors.

The pruning performed in networks reduced the analysis to a subset of the data available, and the citation frequency criteria used to identify the most influential studies may have overlooked recent studies that have not yet accumulated citations. Prior studies have been available for longer periods to the scientific community and thus, have the most opportunity of receiving more citations. Nevertheless, Ramos-Rodríguez and Ruíz-Navarro [97] argued that this could bias the results only to a limited degree because influence is a construct that depends on the passing of time; to be considered influential, a work not only has to accumulate citations but also has to do so over a period of time. In addition, the division of the period into three intervals for evaluating the change in influence may have hidden changes that occurred in each sub-period.

6. Conclusions

In general, prior mapping studies covering themes such as “System Dynamics”, “Software Projects”, “Information System Projects” and “Successful Evaluation Criteria” addressed these topics either in isolation or partially combined. Publications addressing the intersection of the topics were scarce and this work sought to fill this gap by analyzing the evolution of the publications in the period ranging from 1986 to 2015.

From the content analysis and coding performed in this research and shown in Table 7, it was possible to identify the concentration of studies exploring software development projects (34%) or a portion of the development life cycles (31%). There is a gap regarding studies that explore the implementation and post implementation phases of information systems, involving the interaction with end users, maintenance, evolution and the evaluation of the return on investments. Although there is increasing discussion about the perception of complexity introduced by social factors, only a few studies explore the social components associated with software and information system projects, the majority of the studies focusing on the technical aspects of the projects. These social factors comprehend the interactions of software and information systems with individuals, groups, and organizations through their lifecycles, and they happen in a dual-way as both, technical and social elements, can be simultaneously affected along the system’s design, implementation, operation, and maintenance phases. Gerogantzas and Katsamakas [55] argue that system dynamics can help evaluate and model the complexities that arise from the interplay through the time of technical components, people with bounded cognitive capacity, and organizational components.

Moreover, it was also possible to identify that most of the studies presented the construction and simulation steps of the modeling process, used casual loop diagrams and presented simulation results; however, few of them exhibited stock and flow diagrams, and model equations. Besides, there is a concentration of papers assessing success by the system quality perspective, leaving a gap for future studies to explore other dimensions of success in greater depth.

These findings related to the lack of information and details are important for developing new research based on previous studies and consist in one of the most significant obstacles because they hinder the reproduction of past researches due to the lack of well-documented procedures [32,53,118]. This concern was also expressed by Rahmandad and Sterman [95], who found that the majority of the studies reporting results from simulation models, published between 2010 and 2011, lacks model equations, parameter values to replicate the base case, parameter units, or the information needed to replicate a reported graph.

Although there is growing interest regarding complexity in projects context [24,56,61], there was a downward trend in publications in the last period (P3 – 2006–2015), when a growth of interest was expected for research using the system dynamics approach to explore the dynamic complexities involved. Among the identified studies, none of them explored agile methods, which have been seen as a set of approaches for dealing with software project complexity.

Inevitably, this work has limitations, some originating from the research design and other intrinsic of bibliometric analysis.

Future studies should be conducted to confront and to empirically validate and reproduce the results presented here, expanding the search criteria by including other databases, other types of publications and any other work overlooked in this study. Other analytical techniques, such as semantic analysis or other coding structures could be applied to identify other characteristics.

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Appendix A. Articles codification ordered by publication year and citation count

The references cited in this table are [4–6,8,9,11–14,20,22,33,34,37,42,43,54,66,69,70,75,77,79,80,87,88,90,92,94,96,98,101–104,108,112–114,117,128].

			C1							C2		C3				C4				C5						C6					C7					
ARTICLES	JIF	TC	KS1	KS2	KS3	KS4	KS5	KS6	KS7	AP1	AP2	MS1	MS2	MS3	MS4	T1	T2	T3	T4	P1	P2	P3	P4	P5	P6	S1	S2	S3	S4	S5	SD1	SD2	SD3	SD4	SD5	SD6
Ali et al. (2015)	1.046	0	■			■	■			■				■					■		■		■							■						■
Matalonga et al. (2014)	1.143	0	■			■	■			■				■			■		■			■						■				■				
Dutta et al. (2014)	3.392	0	■			■				■					■		■	■	■						■				■	■						■
Stantchev et al. (2013)	2.273	1		■							■				■	■			■				■		■				■				■			
McLeod and Doolin (2011)	1.654	0	■				■				■	■				■					■						■					■	■	■	■	
Remus (2012)	1.087	0					■				■	■				■					■								■					■	■	
Dedrick et al. (2010)	4.917	2									■	■													■					■						
White (2011)	1.758	0	■			■				■				■				■	■								■					■				
Fryling (2010)	4.771	6	■			■	■			■					■	■	■		■						■				■	■		■		■	■	■
Rahmandad and Hu (2010)	1.073	2	■			■									■	■	■	■				■				■						■				
Ferreira et al. (2009)	1.245	10				■	■			■				■		■	■		■		■					■						■		■	■	
Choi and Bae (2009)	1.328	9	■			■					■			■		■		■	■		■					■						■		■	■	
Rahmandad and Weiss (2009)	1.073	6	■			■	■			■					■	■	■		■				■		■			■				■			■	
Luna-Reyes et al. (2008)	1.073	7	■				■				■				■	■	■		■		■					■						■		■	■	
Georgantzas and Katsamakas (2008)	1.073	3			■						■																									
Rodriguez et al. (2006)	1.221	12					■		■	■	■			■					■	■							■									
Garud and Kumaraswamy (2005)	5.405	78					■	■			■	■									■									■				■	■	■
Luna-Reyes et al. (2005)	1.654	24					■				■	■				■	■		■							■						■		■	■	■
Dutta and Roy (2005)	1.925	18				■				■				■		■	■	■	■						■					■			■			■
Barros et al. (2004)	1.245	15							■	■				■				■		■							■					■				
Pfahl et al. (2004)	1.328	14							■	■									■	■							■									
Pfahl et al. (2003)	2.610	7							■	■									■	■							■									
Akkermans and Helden (2002)	1.654	161					■	■			■	■				■					■								■			■		■	■	
Robinson (2002)	1.169	24		■							■												■						■			■				
Lyneis et al. (2001)	1.073	57					■				■				■	■	■		■					■	■		■					■				
Aguilar-Ruiz et al. (2001)	1.328	35				■				■					■				■			■				■						■				
Houston et al. (2001)	1.245	24				■				■	■				■	■			■					■		■						■		■	■	
Pfahl et al. (2001)	1.245	18					■		■	■				■		■			■	■							■					■				
Martin and Raffo (2001)	1.245	16				■			■	■				■			■		■			■				■						■				
Ruiz et al. (2001)	1.245	11	■								■			■		■		■	■	■		■		■		■						■				
Stallinger and Grünbacher (2001)	1.245	10				■			■		■				■				■		■					■								■	■	■
Kahen et al. (2001)	1.245	8		■	■						■				■		■	■	■						■				■			■			■	■
Pfahl and Lebsanft (2000)	1.328	25	■							■					■	■		■	■		■	■					■					■				
Bordetsky and Mark (2000)	4.276	12		■							■			■				■	■	■										■				■	■	
Collofello (2000)	1.221	6					■				■								■	■							■									
Abdel-Hamid et al. (1999)	5.405	33							■	■					■				■	■	■				■		■					■				
Lehman and Ramil (1999)	1.245	21					■			■					■			■	■			■							■			■		■	■	
Rus et al. (1999)	1.245	16	■											■			■		■			■		■			■					■				
Wernick and Lehman (1999)	1.245	16	■				■			■	■			■			■		■					■			■					■				
Powell et al. (1999)	1.245	15	■								■		■			■	■						■					■				■				
Sengupta et al. (1999)	2.440	14							■					■		■	■	■	■	■						■						■				
Pfahl and Lebsanft (1999)	1.245	9	■				■				■			■		■	■		■			■	■	■		■						■		■	■	
McCray and Clark (1999)	1.073	9							■	■					■	■			■				■		■				■	■			■		■	■
Williford and Chang (1999)	1.245	7	■			■	■			■					■		■		■					■	■				■				■		■	
Rodrigues and Williams (1998)	1.272	24	■				■				■		■			■							■			■						■				
Lin et al. (1997)	1.245	23					■			■					■	■		■	■		■			■			■					■				
Rodrigues and Williams (1997)	1.654	16	■				■				■			■		■							■		■		■					■				
Sengupta and Abdel-Hamid (1996)	2.440	17							■		■			■		■		■				■	■				■					■				
Sengupta and Abdel-Hamid (1993)	2.524	71							■	■					■	■		■	■		■							■				■				
Abdel-Hamid (1993)	1.245	13	■						■		■				■	■	■	■	■			■		■				■				■				
Abdel-Hamid (1990)	1.408	11				■	■			■					■	■		■	■					■		■						■				
Abdel-Hamid (1990)	1.245	11				■	■			■					■	■		■	■					■		■						■				
Abdel-Hamid (1989)	2.292	59				■	■			■					■	■	■	■	■		■						■					■				
Abdel-Hamid and Madnick (1989)	2.863	44					■			■					■	■			■		■			■			■					■				
Lin and Levary (1989)	2.292	12	■	■							■			■		■			■			■					■					■				
Abdel-Hamid (1988a)	1.245	18					■			■					■	■		■	■		■			■			■					■				
Abdel-Hamid (1988b)	5.405	9				■	■			■					■	■	■		■			■	■			■						■				
Abdel-Hamid and Madnick (1987)	1.788	11				■	■			■					■	■		■	■					■		■						■				
Abdel-Hamid and Madnick (1986)	1.408	15	■			■				■					■	■		■	■					■		■						■				
TOTALS			22	5	2	21	29	2	13	32	27	6	2	19	27	36	21	22	46	10	16	13	11	15	12	18	20	5	10	8	0	43	5	14	18	9

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