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Behind the scenes: Understanding the socio-technical barriers to BIM adoption through the theoretical lens of information systems research

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1. Introduction

The Architecture, Engineering and Construction (AEC) industry consists of a fragmented and multidisciplinary network with various project participants involved (Grilo et al., 2013; Rizal, 2010). The highly complex nature of the construction value chain often results in quality problems due to errors and defects, time and cost overruns as well as the extensive use of resources (Kerosuo, 2015). The adoption of Building Information Modelling (BIM) can help the AEC industry to overcome these deficiencies by improving design, collaboration and communication (Azhar, 2011; Eastman et al., 2011; Kerosuo, 2015). But despite the numerous benefits as well as the given maturity of BIM, many companies are still reluctant to its adoption (Barlish and Sullivan, 2012; Becerik-Gerber and Rice, 2010).

Over the past decade, many BIM studies have addressed this issue and identified a plethora of technological, legal, economic and social barriers. In examining the barriers to a widespread adoption of BIM, previous literature predominantly focuses on providing quantitative results from single countries, such as China (Jin et al., 2017; Li et al., 2017), Australia (Hosseini et al., 2016; Newton and Chileshe, 2012) or the UK (Eadie et al., 2013, 2014). However, there are so far neither attempts at investigating the barriers from a more global perspective, nor are there theoretically founded explanations, which again are critical to the development of strategies for bridging these. Notwithstanding the fact that BIM constitutes an interdisciplinary research area at the interface between various disciplines, such as information systems (IS), construction informatics and construction management, it has been largely neglected in mainstream IS research and is rather assigned to engineering disciplines with a highly technological focus (Merschbrock and Munkvold, 2012).

Given the high relevance of BIM as one of the most promising technological developments for the AEC sector (Eastman et al., 2011, p. 1; Merschbrock and Munkvold, 2012), the lack of interest in IS research is surprising and prompted researchers to appeal to the IS community to strengthen its contribution to BIM research (Merschbrock and Munkvold, 2012). As the barriers experienced during BIM introduction processes in the AEC industry indeed resemble those experienced during technology adoptions in other industries, the existing body of knowledge in the IS domain can provide substantial insights into the well-researched dimensions of IS adoption. Motivated by the above, we aim to answer the following research questions (RQ):

RQ1: *What are the most frequently reported barriers to a widespread adoption of BIM within the global AEC industry in scientific and practical literature?*

RQ2: *How can these barriers be explained by means of established theoretical foundations from IS research to enhance the understanding of their implications for practice and research?*

Following the plea for more attention in IS research, our work aims at answering the questions from an academic perspective and across geographical and disciplinary borders by turning the well-established knowledge base from the IS domain to account. Therefore, we make use of the multi-method research approach "profoundisation" (Langdridge and Hagger-Johnson, 2009, p. 480; Mayring, 2001), which enables us to combine the strengths of quantitative and qualitative methods. After an introduction of the theoretical background and a brief description of the BIM technology through the lens of socio-technical theory (STT), we thus conduct a meta-analysis of scientific and practical studies that quantitatively address the barriers of BIM. Subsequently, the results are presented by means of a cluster analysis within the context of the STT framework. By means of this step, we capture the holistic nature of BIM prior to providing the theoretical foundations of each barrier dimension based on findings from a literature review. Finally, we provide a discussion of results and concluding remarks.

2. Theoretical background

2.1. State of the art of BIM

By definition, BIM is an innovative technology to virtually design and manage construction projects by simulating a virtual model of a building (Azhar, 2011; Eastman et al., 2011, p. 1). Through the provision of relevant information (schedule, cost estimates, material inventories, geometry and spatial relationships), BIM allows all project members to efficiently collaborate throughout the whole project life-

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cycle (Azhar, 2011). Meanwhile, BIM is considered as one of the central technologies for the digitisation of the construction value chain, as it is the key enabler for many other future technologies. The building of a bridge, for example, can be facilitated by combining robotics and 3D printing via parametrically designed 3D models (de Almeida et al., 2016, p. 10). Given its interdisciplinary and interorganisational nature, BIM can be considered as an Interorganisational Information System (IOIS) facilitating information exchange and collaboration across company borders (Bosch-Sijtsema et al., 2017).

The origins of BIM can be traced back to the first conceptual ideas for object-based design, relational databases and parametric manipulation established by Engelbart (1962) in the 1960s. In his visionary work, Engelbart describes a detailed scenario in which an architect enters a series of specifications and data of a floor, a concrete wall and other components in order to create and iteratively adjust a virtual model that can be displayed on the monitor screen of a computer workstation. After finishing the model of the building, detailed information about the interior is entered, including fixture designs and a functional analysis of the building. This functional analysis includes the computational simulation of the occupant's daily sequences of activities in order to identify potential conflicts (Engelbart, 1962, pp. 4–5). Almost 40 years later, the advent of the first available BIM software in 2000 marked the beginning of an industry-wide popularity within the architecture, engineering and construction (AEC) industries (Merschbrock, 2014, p. 10). Today, a plethora of BIM applications are commercially available (Roland Berger, 2017).

Technologically, BIM constitutes a very broad concept with different dimensions that in turn are associated with new challenges. In order to form the basis for an enhanced understanding towards the socio-technical barriers of BIM, it is necessary to refer to its different maturity levels. BIM maturity levels define the minimum requirements that an organisation must reach to be considered as successful in achieving this level (Succar, 2010). The starting point of the maturity model shown in Fig. 1 is the pre-BIM level, which represents the industry status prior to the introduction of BIM. Communication and collaboration are based on paper, 2D and 3D CAD drawings, and there is a complete lack of interoperability among the exchanged information. To be in BIM level 1, an organisation must have implemented a 3D parametric software tool in which basic data export features are available to enable file-based data-exchanges and collaboration based on 3D visualisations and prints. The move from the pre-BIM status to Level 1 is therefore primarily a technical undertaking, since the social challenges that arise from close collaboration and communication do not emerge in this level. This is rather the case in BIM level 2 that refers to a model-based collaboration across disciplines based on one single model. In level 2, interoperability is achieved through the exchange of models and sub-models using IFC files, while collaboration is enabled through the shared use of collaborative models that allow semantic BIM interchanges but also raise questions about contractual and legal issues. Full interoperability, collaboration and communication is achieved in BIM level 3, in which organisations share object-based models in a central repository to ensure continuous validation. In BIM levels 4 and 5, further dimensions are added to the model such as time (Level 4) and cost information (Level 5) in order to enable an improved construction sequence planning and cost management throughout the design- and construction process. Therefore, cost information, project history and operational documentation are directly linked to the objects of the model (Roland Berger, 2017). As already acknowledged by extant research, the efforts needed to achieve the different BIM stages are considered substantial (Succar, 2010). As also indicated by the BIM maturity model in Fig. 1, the degree of complexity grows with each BIM maturity level, since the increases in content, interoperability and collaboration pose new technical and social challenges to the adoption process.

Although companies from the global AEC sector show an increased awareness towards BIM, in many countries the overall BIM adoption rates are progressing more slowly than anticipated (NBS, 2016) and differ considerably from country to country: only 16% of the construction companies in the UK do not use BIM, while in Austria the figure is 49% (de Almeida et al., 2016, p. 25). Early adopters of BIM are foremost large construction firms, whereas small and medium enterprises (SME) show less engagement towards BIM adoption (McGraw Hill Construction, 2014, p. 15; Merschbrock and Munkvold, 2012; NBS, 2016). In recent years, governments across the globe have taken initiatives to facilitate the nationwide implementation of BIM in their countries (McAuley et al., 2017). For instance in Norway, Finland and Denmark, BIM is officially mandatory for government construction projects to provide the necessary incentives for BIM adoption. In the UK, BIM Level 2 has become obligatory for all centrally-procured construction projects since 2016. Other countries follow these examples by setting up new mandates, such as the German government's goal to make BIM mandatory for the planning and realisation of large-scale

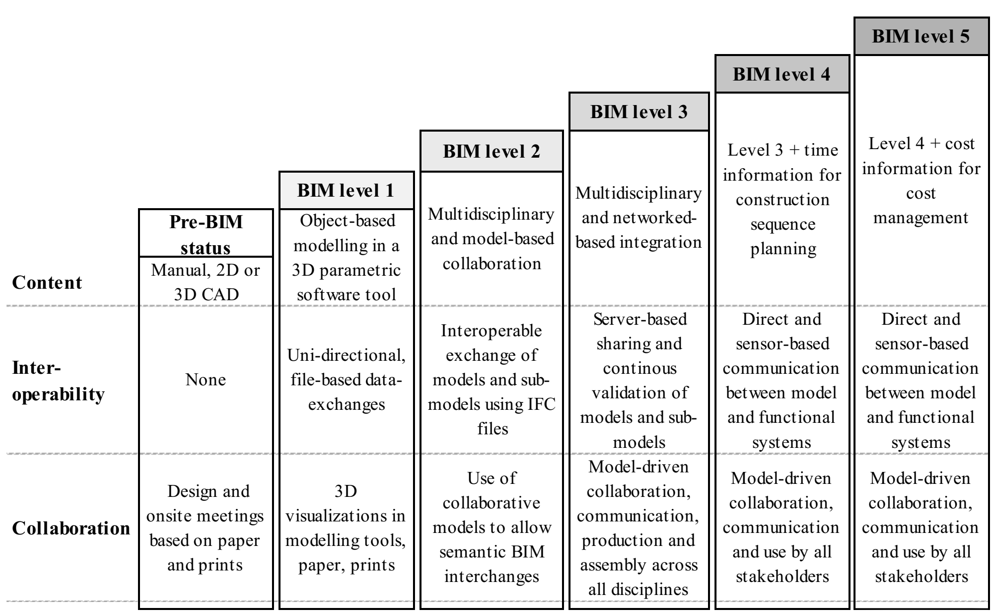

Fig. 1. BIM maturity model based on Lee et al. (2016); Poljanšek (2017); Roland Berger (2017); Succar (2010).

infrastructure projects from 2020 onwards. The global attempts in accelerating BIM adoption underline the importance of this technology for the AEC industry.

2.2. BIM through the lens of socio-technical theory (STT)

When comparing the different definitions of BIM, a general shift away from the isolated view of BIM as a technology-centric topic (Azhar, 2011; Eastman et al., 2011, p. 1) towards the socio-technical view of BIM as an IS (RICS, 2014) can be detected. From a socio-technical point of view, "*Building information modelling (BIM) gets people and information working together effectively and efficiently through defined processes and technology*" (RICS, 2014). By emphasizing the key factors "*people, information, processes, technology*", this definition of BIM makes clear that BIM is not only a software, but a combination of social and technical factors.

According to STT, every IS consists of a technical subsystem comprising all processes, tasks and technology components required for running the system as well as a social subsystem which is concerned with the structure of the work-system, the employees and their attitudes, knowledge, skills, values and interrelationships (Bostrom and Heinen, 1977), cf. Fig. 2.

Through the lens of STT, the actors of the social system of an IS are individuals or groups from the organisational environment who "*have a stake or can set up a requirement towards the organization*", which includes employees, managers, users as well as customers, subcontractors and suppliers (Lyytinen and Newman, 2008, p. 596). The structure of the social system, on the other hand, is defined by institutional arrangements, such as formal work organisation, communication and authority structure, including values, norms, general role expectations and behavioural patterns (Lyytinen and Newman, 2008). The technology component of the technical system comprises the required soft- and hardware, the infrastructure as well as methods and tools necessary for the implementation process. The tasks by which organisational goals, purposes and stakeholder requirements are achieved form the second component of the technical subsystem (Lyytinen and Newman, 2008).

As it is assumed that both subsystems interact, a joint focus is fundamental for identifying and solving the problems towards IS adoption (Bostrom and Heinen, 1977). Through the lens of STT, we aim to achieve an enhanced understanding of the barriers towards BIM adoption by examining the impact level of each barrier as well as its causes.

3. Meta-analysis procedure

Meta-analysis has become an important research method in various research disciplines such as psychology, medicine, economics and political science (Hunter and Schmidt, 2004, p. 32). The strength of this research method is its ability to quantitatively compare findings across a large number of studies and thus to create new knowledge based on the consolidated results (Hunter and Schmidt, 2004, p. 26). Within the IS discipline, meta-analysis has been applied in an increasing number of studies for multiple purposes, e.g. for examining the dependencies between IT investment and company performance (Kohli and Devaraj, 2003; Liang et al., 2010; Lim et al., 2004), for comparing the results of previous research using the Technology Acceptance Model (King and He, 2006; Legris et al., 2003; Schepers and Wetzels, 2007) or for investigating gender differences in computer-related attitudes and behaviour (Whitley, 1997).

In this paper, we aim to apply meta-analysis as a means to summarise the empirical results from previous studies addressing the barriers to BIM adoption. In doing so, our primary goal is neither to test hypotheses nor to examine the dependencies between model variables, but rather to synthesize the research findings and to provide a more comprehensive view of BIM barriers across geographical borders prior to providing further implications for research and practice. Following the meta-analysis procedure proposed by Glass et al. (1981) and Hunter and Schmidt (2004), our research process comprises a set of steps as illustrated in Fig. 3.

The procedure starts with the definition of the problem, including the development of a framework and factors that helps us to answer the posed research questions. In the following, the successive steps of the meta-analysis procedure are explained in detail.

3.1. Selection of relevant studies

The second step of the procedure consists of a comprehensive literature search in various databases as well as a forward and backward search in all relevant studies as described by Hunter and Schmidt (2004, p. 467). Since BIM is positioned at the interface between diverse disciplines (Merschbrock and Munkvold, 2012), we first conduct our search in interdisciplinary databases such as Scopus, Business Source Complete, ScienceDirect, Ingentaconnect and SpringerLink and subsequently broaden our search by accessing the GoogleScholar database. To search for more practical studies (e.g. surveys, reports and commercially-driven studies from consulting firms), we additionally conduct an open Google search. The key phrase applied for the database search includes the specific search string ("building information modeling" OR "building information modelling" OR BIM OR "virtual design and construction") AND (barrier* OR obstacle* OR challenge* OR constraint*) AND (survey OR report OR study OR questionnaire) as well as the more general search phrase ("building information modeling" OR "building information modelling" OR BIM) AND (survey OR report OR study) for the Google search. Prior to conducting the Google search, we have made every effort to avoid potential biases towards the search results by deleting search history and cookies within the browser. Subsequently, we use the incognito mode of our browser to perform the literature search.

Our initial search results in 71 studies published in journal papers, conference proceedings as well as book chapters and additional 61 studies published in reports or white papers of consulting firms (e.g. the annually published SmartMarket Report of McGraw Hill Construction) or non-profit organisations (buildingSMART BIM surveys). Those contributions that meet the inclusion criteria listed in Table 1 are included in the final sample.

In order to identify the main barriers to BIM adoption, an initial quantitative summary of all reported barriers is required. To accomplish this, it is necessary that the identified contributions meet scientific standards and provide reliable information, e.g. sample sizes and response rates. Furthermore, as Likert scales (Likert, 1932) allow to measure perceptions and attitudes towards certain topics (Allen and Seaman, 2007) and are considered as a recognized valuation method, we chose the questionnaire design based on a Likert scale to be another decisive criterion for our selection. Besides, the studies must be written

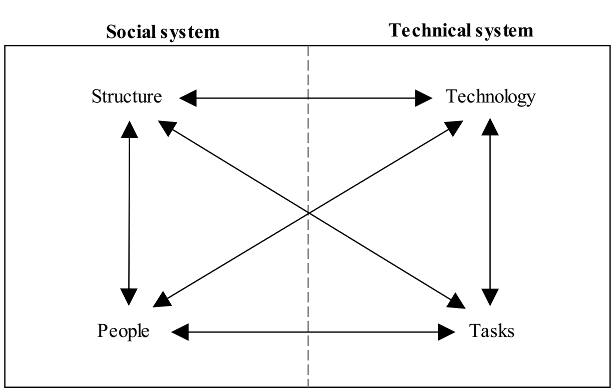

Fig. 2. The STT framework, adapted from Bostrom and Heinen (1977).

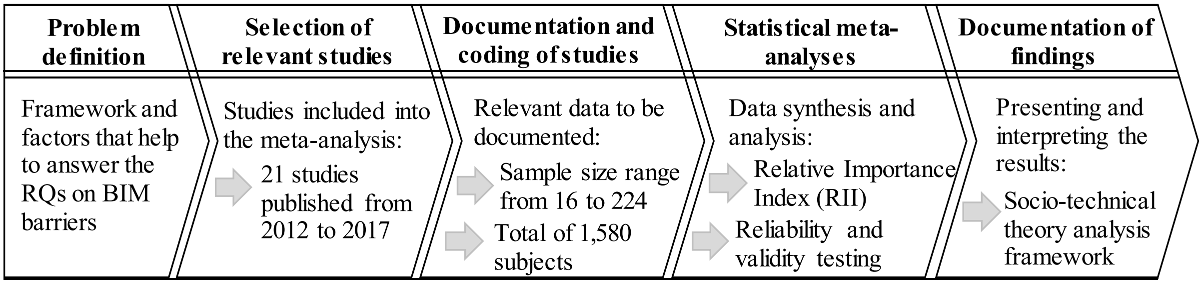

Fig. 3. Meta-analysis procedure adapted from Glass et al. (1981) and Hunter and Schmidt (2004).

in English and published in journal papers, conference proceedings, dissertations or as reports. For reasons of compatibility, we deliberately excluded those studies that use simple questionnaire techniques (e.g. multiple choice) or are written in another language than English.

This selection process led to a final sample of 21 studies (from 2012 through 2017) addressing the perception of professionals from 12 countries and 4 continents.

3.2. Documentation and coding of study characteristics

In the next step, the selected studies are documented and coded in Excel sheets with respect to their relevant characteristics and empirical data (e.g. country, sample size, response rate) as well as the survey data, which provide information on the items (adoption barriers) and the respondents' aggregated rating for each barrier based on a Likert scale. Given the different analysis and presentation methods, some effort is needed to align the information. To be more specific, most studies apply the Relative Importance Index (RII) to analyse the survey data from the Likert scales according to the following formula (Eadie et al., 2013; Holt, 2014):

$$RII = \frac{\sum W}{AN} \; (0 \leq index \leq 1) \tag{1}$$

where:

- W = the weighting given to each element by the respondents as the sum of scores for a variable (V_i) from N respondent sample.
- A = the highest weight (largest integer) on the response scale (A_{max} in the present study).
- N = the total number of respondents (sample size).

In several studies the authors do not use the RII, but rather weighted Mean Scores or the original ratings to analyse the survey data. For example, Li et al. (2017) use the Mean Score according to the following formula, which is slightly different from the RII:

$$Mean\ Score = \frac{\sum W}{N} \; (1 \leq Mean\ Score \leq A) \tag{2}$$

where researchers only published the original rating scores for the items of the survey, we calculate the Mean Score and RII for the survey data according to the presented formulas (1)–(2). For all studies, we document the data necessary for the final consolidation of results, such as W, A, N, RII and Mean Score. In the event that only the RII or Mean Score is available, we derive ΣW according to formulas (3) and (4):

$$\sum W = Mean\ Score \times N \tag{3}$$

$$\sum W = RII \times AN \tag{4}$$

By using RII, Mean Score or other parametric measures for analysing Likert scale-based survey data, researchers assume that the ratings based on Likert scales form an interval scale so that parametric statistical tests can be applied to provide more objective interpretations compared to nonparametric alternatives (Allen and Seaman, 2007). As has been argued by many researchers from across diverse disciplines, Likert scale data can be treated as interval data and effectively analysed using parametric tests when the series of questions can be combined to measure a particular trait (Boone and Boone, 2012), or when the sets of the Likert items can be combined to form indexes (Brown, 2011). The meta-analysis conducted in this paper is also based on this assumption.

3.3. Statistical meta-analyses

The step of statistical meta-analyses comprises two major tasks: The integration of studies and the accumulation of findings. Hunter and Schmidt (2004, p. 445) provide a comprehensive overview of available methods for the integration of studies that covers less efficacious methods such as the narrative procedure or the vote-counting methods as well as more efficacious methods such as the psychometric meta-analysis method that enables an understanding and correction of diverse kinds of biases (e.g. sampling error, measurement error). Although often recommended for testing the reliability, homogeneity and validity of the data, for our purposes it is of no benefit to conduct statistical methods, since we do not aim to examine the correlation between certain variables nor to test hypotheses, but rather to summarise the weighted ratings from Likert scale survey data. Furthermore, for conducting statistical methods, in many cases additional data is needed that is not available in all studies. For example, to calculate the Cronbach's alpha coefficient (α) for proving the internal consistency reliability for the scales used, we would additionally need the standard deviation for each item and the standard deviation of the whole sample of the items. However, that information is available in only 6 studies. Therefore, we focus on integrating the collected data as presented in the

Table 1
Inclusion and exclusion criteria for the selection of relevant studies.

Inclusion criteria	Exclusion criteria
• Studies based on a questionnaire design using a Likert-scale and addressing the barriers, obstacles, constraints or challenges to BIM adoption	• Studies based on questionnaire design using simple multiple-choice questions • Expert interviews and other questionnaire designs
• Relevant information is available (sample size, response rate, empirical data)	• Studies lacking relevant empirical results, studies with incomplete results and duplicates
• Studies published in English language • Studies published in journal papers, conference papers, books, dissertations and reports	• Studies published in other languages • Studies from bachelor and master theses

Table 2
Examples of the assignment procedure.

Item	Adoption barrier	Impact level
• The cost of BIM training is significant to our firm (Hosseini et al., 2016)	High investment costs	Tasks
• No enforcement from client (Memon et al., 2014)	Lack of demand	Structure
• People resistance on change and organisational change (Venkatachalam, 2017)	Resistance to change	People

previous section (W, A, N, RII and Mean Score).

The meta-analyses are conducted by using the Excel-based statistical software XLSTAT Version 2017.5. Since the coding process of the included studies is already performed by using Excel sheets, XLSTAT enables a simple and seamless data analysis. To further summarise our findings, we define clusters for the adoption barriers as well as their impact level for each item prior to applying cluster analysis and aggregating the statistical data (Kaufman and Rousseeuw, 2009). The assignment process is explained in the examples as presented in Table 2.

First, the barriers indicated in each study need to be categorised. For example, the item "*The cost of BIM training is significant to our firm*" (Hosseini et al., 2016) is assigned to the cluster *"high investment costs"*. Additionally, each adoption barrier is assigned to one of the dimensions of the STT framework *structure, people, tasks or technology* (cf. Section 2.2). To remain with the above example, the adoption barrier "*high investment costs*" is allocated to the STT framework dimension "*tasks*", as tasks are to be completed in the system in order to achieve the goals, purposes and stakeholder requirements (Lyytinen and Newman, 2008). As a final step, the sum of the collected data (W, AN, N) is calculated for each adoption barrier in order to analyse the RII according to the formulas (1)–(4) as presented in the previous section. The empirical results of the meta-analysis are presented in Section 4.

4. Empirical results

4.1. Descriptive statistics

The empirical results of this meta-analysis have a broad geographic reach: The 14 journal papers, 6 conference papers and 1 book chapter published between 2012 and 2017 stem from a total of 12 countries and 4 continents (cf. Table 3). Interestingly, 12 of the 21 studies focus on investigating adoption barriers in Asian countries (e.g. China, Hong Kong, Malaysia, Saudi Arabia), while 4 studies concentrate on Africa (Nigeria) and only 5 studies on more developed regions (Sweden, UK, Australia). Thereby, the study populations range from construction, design as well as consulting firms, SMEs, municipal project participants and other professionals from the construction industry.

Table 4
Descriptive statistics for the included studies (N = 21).

	Population size	Sample size (N)	Response rate	Number of items
Minimum	30.0	16.0	9.9%	5.0
Maximum	1365.0	224.0	87.1%	20.0
Median	119.0	55.0	49.0%	10.0
Mean	211.9	73.8	48.7%	11.2
Standard deviation (n − 1)	289.6	49.6	20.1%	3.9

As can be seen from Table 4, the studies' sample sizes vary from 16 to 224 respondents, while the population sizes range from 30 to 1365 participants, which results in a total sample size (ΣN) of 1549 respondents and a population size of 4450 participants. The resulting response rate of 34.8% is satisfactory considering the scientifically recommended minimum threshold of 30% (Baruch and Holtom, 2008; Moser and Kalton, 1971). The items of each study range between 5 and 20, with a total of 236 data sets presented in different measures, such as Mean Score, RII or original ratings (cf. Table 3).

It is clear from Fig. 4 that there has been a growing interest towards the topic "*BIM adoption barriers*" since 2012. Given the fact that the first available BIM software was launched in 2000 (Merschbrock, 2014, p. 10), it is understandable that the first studies on the adoption barriers of BIM appear in 2012, since the adoption of BIM is considered a complex and time-consuming undertaking similar to the implementation of ERP systems (Merschbrock and Munkvold, 2012).

In summary, it can be stated that our meta-analysis has a sound basis on which BIM barriers can reasonably be examined.

Table 3
Studies included into the meta-analysis.

#	Study	Publication type	Geographical context	Population size	Sample size (N)	Response rate	# of items	Data
1	Abubakar et al. (2014)	Conference paper	Nigeria (Africa)	100	49	49.0%	12	RII
2	Ahmed et al. (2014)	Conference paper	Quatar (Asia)	203	54	26.6%	17	RII
3	Alhumayn et al. (2017)	Book chapter	Saudi Arabia (Asia)	342	224	65.5%	9	Original ratings
4	Bosch-Sijtsema et al. (2017)	Journal paper	Sweden (Europe)	104	32	30.8%	15	Mean score
5	Chan (2014)	Journal paper	Hong Kong (Asia)	137	52	38.0%	12	Mean score
6	Eadie et al. (2013)	Journal paper	UK (Europe)	119	92	77.3%	10	RII
7	Eadie et al. (2014)	Journal paper	UK (Europe)	74	30	40.5%	10	RII
8	Enshassi et al. (2016)	Journal paper	Palestine (Asia)	75	37	49.3%	17	RII
9	Ezeokoli et al. (2016)	Journal paper	Nigeria (Africa)	84	56	66.7%	8	RII
10	Hamadaa et al. (2014)	Journal paper	Iraq (Asia)	180	72	40.0%	12	RII
11	Hosseini et al. (2016)	Conference paper	Australia (Australia)	1365	135	9.9%	13	RII
12	Jin et al. (2017)	Journal paper	China (Asia)	297	94	31.6%	9	RII
13	Anuar and Abidin (2015)	Journal paper	Malaysia (Asia)	60	48	80.0%	5	Original ratings
14	Li et al. (2017)	Conference paper	China (Asia)	555	136	24.5%	12	Mean score
15	Memon et al. (2014)	Journal paper	Malaysia (Asia)	150	95	63.3%	8	RII
16	Newton and Chileshe (2012)	Conference paper	Australia (Australia)	70	29	41.4%	10	RII
17	Onungwa and Uduma-Olugu (2017)	Journal paper	Nigeria (Africa)	30	16	53.3%	9	Original ratings
18	Ugochukwu et al. (2015)	Journal paper	Nigeria (Africa)	155	135	87.1%	7	Mean score
19	Vasudevan (2016)	Journal paper	Malaysia (Asia)	100	55	55.0%	6	Original ratings
20	Venkatachalam (2017)	Conference paper	United Arab Emirates (Asia)	100	60	60.0%	20	Mean score
21	Zahrizan et al. (2014)	Journal paper	Malaysia (Asia)	150	48	32.0%	15	RII
	Total			4450	1549	34.8%	236	

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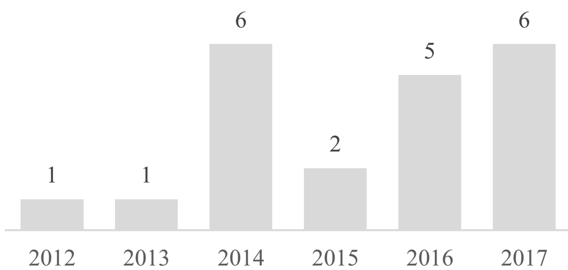

Fig. 4. Number of studies, grouped by year of publication.

4.2. Socio-technical impacts of BIM adoption barriers

In the last step of the meta-analysis, we analyse and present the empirical data. Drawing on the STT framework presented in Section 2.2, we conduct a cluster analysis by grouping the barriers according to their STT impact level and measures[1] and thus enhance the understanding for the adoption barriers (cf. Table 5). Regarding the structural adoption barriers, it appears that *legal and contractual uncertainty (S1)* is the most frequently reported barrier. However, far more important in this cluster are *lack of awareness about BIM (S3)* and *lack of government incentives and regulation (S4)*. Equally important are concerns about the general necessity for BIM, which is expressed through *lack of demand (S2)* or *lack of necessity (S5)*. The last reported barrier of this cluster is the *non-widespread use (S6)* of BIM.

The adoption barriers assigned to the people dimension relate to human factors such as behaviour and skills. Thereby, *resistance to change (P1)* constitutes by far the most frequently cited adoption barrier, while the most important barriers according to the RII affect corporate resources: *lack of skilled personnel (P3)*, *lack of expertise (P2)* and *lack of training (P4)*. Further key barriers to an effective BIM use (Eadie et al., 2013; Li et al., 2017) are *lack of management support (P6)* and *lack of information sharing, collaboration and trust (P5)*. A closer look at the technology dimension reveals a wide range of essential technical and task-related adoption barriers. For example, the *lack of standards and interoperability (TE1)* is considered as a key constraint. Above this, BIM is criticised for its *time-consuming adoption (TE4)*, *lack of applicability and practicability (TE5)* and *poor quality of model information (TE7)*. Further obstacles are the *complexity of BIM (TE3)*, the limited *availability of BIM (TE6)* and the *insufficient infrastructure (TE2)*.

When comparing the RII of the different STT clusters (cf. Fig. 5), it must however be concluded that technology-related adoption barriers are rated as rather less critical. The task dimension of the technical subsystem aims at fulfilling corporate goals, purposes and stakeholder requirements (Lyytinen and Newman, 2008). Hence, task-related barriers prevent organisations from adopting BIM for strategic and economic reasons. The most frequently cited barriers in this cluster are *high investment costs (TA1)* and the associated barrier *lack of proven benefits (TA2)*, whereas the *lack of investment capital (TA3)* constitutes the barrier with the highest RII. In general, the high costs of BIM are an often criticised obstacle especially for SMEs with limited investment capital (Hosseini et al., 2016; Li et al., 2017).

This finding can be confirmed when regarding the frequency of the coded items assigned to the four STT dimensions (cf. Fig. 6). With a total of 134 coded items, the most frequently reported adoption barriers relate to the social subsystem (Structure = 65, People = 69), while only 102 are attributable to the technical subsystem (Technology = 43, Tasks = 59).

To sum up, there is a wide range of structural, social, technological and task-related BIM barriers which, apart from a slight tendency towards the social aspects, are relatively evenly distributed to the dimensions of the socio-technical system (cf. Fig. 6).

[1] A complete overview of the coded data as well as their corresponding references can be found at http://bit.ly/2FEWx7A

Table 5
Cluster analysis of adoption barriers according to STT impact dimensions.

Impact level		Coded items	Σw	AN	N	RII
Structure dimension						
S1	Legal and contractual uncertainty	19	4115	5996	1156	0.686
S2	Lack of demand	17	5604	7530	1506	0.744
S3	Lack of awareness about BIM	11	2556	3282	643	0.779
S4	Lack of government incentives and regulation	9	2463	3190	638	0.772
S5	Lack of necessity	6	1398	2110	422	0.662
S6	Non-widespread use	3	515	723	123	0.713
Total		65	16,651	22,831	4488	0.729
People dimension						
P1	Resistance to change	24	5228	7144	1427	0.732
P2	Lack of expertise	16	4781	6185	1264	0.773
P3	Lack of skilled personnel	10	2951	3743	727	0.788
P4	Lack of training	8	1551	2153	409	0.721
P5	Lack of information sharing, collaboration and trust	6	1295	1968	372	0.658
P6	Lack of management support	5	926	1285	257	0.721
Total		69	16,732	22,478	4456	0.744
Technology dimension						
TE1	Lack of standards and interoperability	19	4734	6604	1292	0.717
TE2	Insufficient infrastructure	6	686	1134	234	0.605
TE3	Complexity of BIM	5	1516	2318	442	0.654
TE4	Time-consuming adoption	5	1944	2735	547	0.711
TE5	Lack of applicability and practicability	4	987	1320	264	0.748
TE6	Availability of BIM	3	492	787	143	0.625
TE7	Poor quality of model information	1	76	160	32	0.476
Total		43	10,435	15,058	2954	0.693
Tasks dimension						
TA1	High investment costs	33	8509	11,538	2250	0.737
TA2	Lack of proven benefits	24	6879	9703	2027	0.709
TA3	Lack of investment capital	2	678	780	183	0.869
Total		59	16,067	22,021	4460	0.730

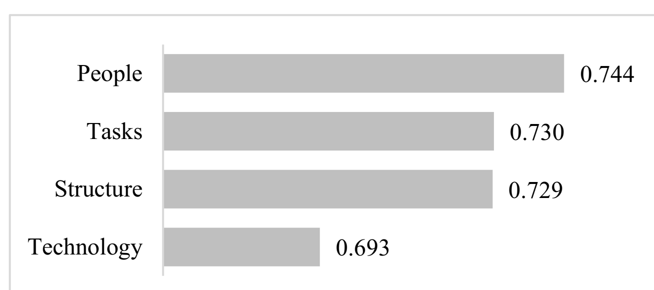

Fig. 5. RII of STT dimensions.

5. Explanatory model

As is evident from the empirical results of the meta-analysis, manifold BIM adoption barriers strongly impact the various STT dimensions. But even though it may seem obvious, the causes for the different barriers cannot automatically be found in the impact dimensions to which they are assigned. For instance, *lack of standards and interoperability (TE1)* constitutes a main technological barrier (Chan, 2014; Enshassi et al., 2016; Li et al., 2017), on closer inspection, however, it is not technologically but rather socially rooted, as the behaviour of the participants involved in the construction network comes into play. Possible explanations can be found in related research

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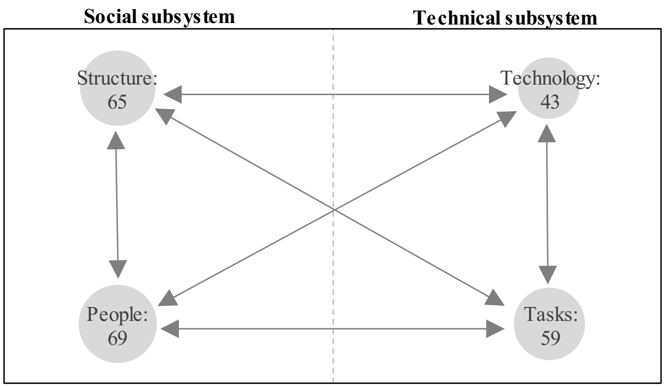

Fig. 6. Impacts of BIM adoption barriers according to STT dimensions by frequency.

streams from the IS domain, e.g. the well-known problems associated with standard-making in Interorganisational Information Systems (Markus et al., 2006; Monge et al., 1998). Thus, it is essential to 'think outside the box' by viewing the background of the barriers through the lens of established theories from the IS domain.

Apart from the empirical findings of the meta-analysis, many authors attempt to suggest potential solutions to overcome the barriers. Remaining with the example of the lack of standards, some authors propose that "*BIM should have a standard code of practices and guideline*" (Anuar and Abidin, 2015) and that this could be achieved through the "*Development of local parametric library embedded in a national BIM server*" (Alhumayn et al., 2017), or by "*Setting out a BIM technology center*" (Vasudevan, 2016) or establishing a "*BIM council/ association*" (Ezeokoli et al., 2016). However, what is still missing is that the authors neither explain the causes for the adoption barriers nor describe why the proposed solutions might be suitable. Hence, instead of providing solutions that cannot be practically implemented, we are firmly convinced that a deeper understanding of the barriers' causes is indispensable to eradicate the problem by its roots and thus to identify adequate solutions. Therefore, we conduct a systematic literature review according to Webster and Watson (2002) in the databases Scopus, Business Source Complete, ScienceDirect, Ingentaconnect and SpringerLink as well as GoogleScholar with the purpose of identifying high quality publications from the IS domain that might be helpful in providing explanations for the barriers presented in the meta-analysis. The key phrases employed for the search process are based on the outcomes of the meta-analysis and consist of different parts as depicted in Fig. 7.[2]

In order to be included in the subsequent content analysis, relevant articles must address explanations as well as solutions for the investigated barriers based on a theoretical foundation from a related research topic in the IS field. For example, publications that can be found when applying the key phrase *("information systems" OR "information technology" OR innovation) AND (barrier OR obstacle OR constraint) AND (adoption OR implementation) AND theory AND (change OR resistance OR acceptance)* must describe a resistance to change and suggestions how to overcome these through the lens of a specific IS theory. Since we do not aim to employ a complete review of the IS literature related to each topic area, but rather to provide empirical evidence from the IS domain, we focus on only selected findings in the subsequent section.

By means of the literature review, we reveal that the topic of adopting innovations has received significant academic attention in the IS domain in the last decades. As a result, we identify a plethora of theoretical foundations and empirical evidence for various topics concerning the barriers and challenges to the adoption of innovations and IT/IS, which we subsequently assign to the different BIM adoption barriers as listed in Table 5. Thereby, we provide proper explanations from the IS domain, deepen the understanding for the barriers and suggest suitable solutions.

5.1. Structure dimension

The most frequently cited structural BIM adoption barriers *legal and contractual uncertainty (S1)* and *lack of government incentives and regulation (S4)* lie in state responsibility. Obviously, it is the task of each government to provide clearly defined legal and contractual regulations and thus to create the macroeconomic environment which also shapes the technological opportunities and capabilities of the operating firms (Arrow, 1962). From a wider economical perspective, there is a common belief that government bodies support the diffusion of innovations by promoting and funding programs and technology transfer or cooperative activities with industry (Moon and Bretschneider, 1997; Smith, 2000). The rationale for this can be found in Arrow's *market failure analysis* (Arrow, 1962), who argues that public subsidies are required to create knowledge and intellectual property rights, because a completely competitive and decentralized market system will lead to an under-supply of knowledge (Smith, 2000). Hence, governmental regulations and the provision of incentives are recommended (Smith,

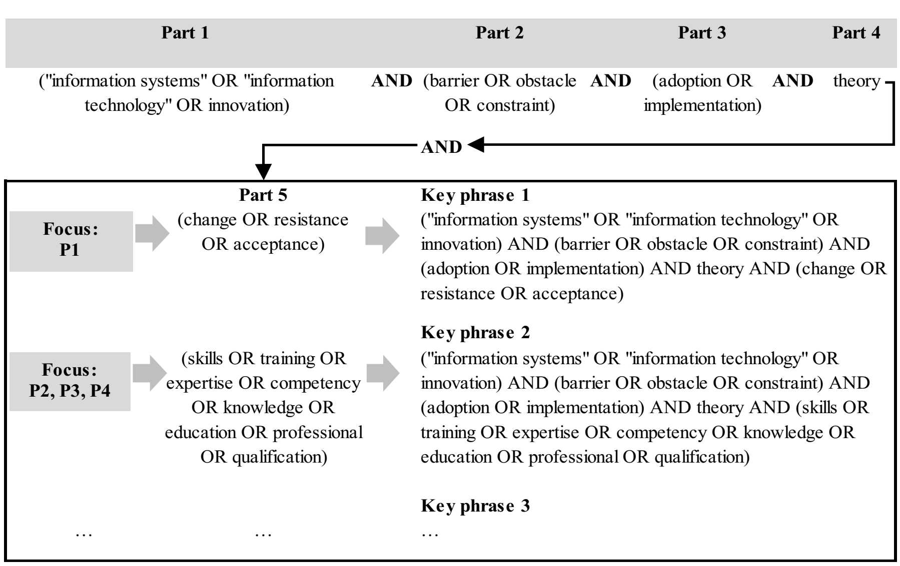

Fig. 7. Key phrases for the literature search.

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2000). Previous research based on the *Technology-environment-framework* (Depietro et al., 1990) confirms this recommendation, but with one major distinction. For example, Zhu et al. (2006b) state that government regulations are a more important factor in developing countries than in developed countries. However, government involvement is associated with high expenditures which is considered critical at a time of public budget constraints (Smith, 2000).

Nowadays, there are several government initiatives supporting technological innovations, e.g. Industry 4.0, Internet of Things and Smart Manufacturing (Kagermann et al., 2013, p. 67). Indeed, it is empirically established that government involvement can provide a decisive momentum for the diffusion of innovations. Such involvements increase the awareness for new technologies by promotional activities, subsidies and an appropriate legal environment (Moon and Bretschneider, 1997). But why are government incentives required? To answer this question, a change of perspective is necessary. According to the *actor-network-theory (ANT)*, the role of standards within the diffusion phase of innovations is crucial, as it enables different actors to (1) coordinate their conflicting interests for building an effective actor network, (2) to integrate and generate technical knowledge required for the adoption and (3) to support the creation and regulation of the domestic and global market. Companies trying to adopt new IT and IS such as broadband mobile services may face barriers that they cannot overcome alone. In IS literature, it has been argued that innovations in "complex technology systems" (such as BIM), are collective achievements of different actors like private companies and government bodies rather than of individual firms (Yoo et al., 2005).

There is a common recommendation for fostering BIM adoption through governmental bodies, including the introduction of promoting BIM mandates and financial subsidies (Alhumayn et al., 2017; Anuar and Abidin, 2015; Chan, 2014; Ezeokoli et al., 2016; Zahrizan et al., 2014) and a corresponding legislation that addresses insurances, product liability risks, ownership and intellectual property (Eadie et al., 2014; Newton and Chileshe, 2012). But despite various supportive governmental measures (implementation strategies, initiatives and BIM mandates), in many countries the overall BIM adoption rates are progressing more slowly than anticipated (NBS, 2016), which may be due to the fact that government mandates fail to have the desired impacts when the required social climate, infrastructure or readiness are lacking (Venkatachalam, 2017).

The *lack of standards and interoperability (TE1)* is considered the most important barrier for a widespread BIM adoption in the AEC sector, since it concerns communication and collaboration (Eadie et al., 2014). Although the need for global and industry-wide standards of BIM has been addressed in many studies (Chan, 2014; Hooper, 2015; Newton and Chileshe, 2012), the AEC industry has not yet managed to establish an industry wide standard (Eadie et al., 2014), which is reportedly due to self-interests, lack of end-user participation and incompatible processes (Hooper, 2015). There is a general tendency in the construction industry to focus on standardization and optimisation at an individual or organisational level while putting less emphasis on the entire process (Poljanšek, 2017). Although this barrier has a technical impact dimension, its causes are rather of social nature and can be assigned to the structure dimension. The lack of standards is a well-known problem in the IS domain that already affected technologies such as RFID or IOIS (Monge et al., 1998). In the case of IOIS, it took three decades to develop and establish multiple process and data standards allowing for information exchange across system and organisational borders (Lyytinen and Damsgaard, 2011). Despite the fact that open standards increase connectivity and interoperability between IS and organisations, their development and diffusion fail in many cases (Markus et al., 2006). Possible explanations for this can be found in psychology, namely in Olson's (1971) *theory of collective action*, according to which standards can be regarded as public goods resulting from the collective action of interested parties. The main problem with this is the non-exclusivity and the free-riding behaviour of parties who did not contribute to the value creation but enjoy the benefits. This is most likely the reason for the modest willingness within the AEC sector to participate in the costly standards developments at the beginning of the standardization efforts.

In examining the conditions for the creation of industry-wide collaborative standards for Vertical Information systems (VIS), extant research from the IS domain provide interesting propositions how to resolve the dilemma. As emphasized by Markus et al. (2006), a successful development of industry wide standards that equally meet the requirements of users (construction companies, project owners, architects, sub-contractors, supplier) and vendors requires the participation of representatives from all industry groups. However, given the divergent interests of users and vendors, this might be challenging. In fact, while vendors prefer proprietary solutions involving competitive advantage, users prefer open standards and a freedom of choice. Furthermore, Markus et al. (2006) underline that the diffusion of the developed standards must be ensured. This could be achieved by involving highly influential participants into the standard development process and by committing them to later adopt the standards, which may set an example for others. In the AEC industry, local governments should also play a vital role in overcoming these barriers by means of enforcing legislative BIM standards and specifications on construction projects (Chan, 2014; Newton and Chileshe, 2012).

In comparing the standardization efforts on BIM with other standardization efforts within the ICT sector, a recent technical report published by the European Commission (Poljanšek, 2017) has emphasized the strong similarities between the AEC and ICT domain. Similar to standardization efforts on other ICT, the development of BIM standards can be divided into three major parts:

- The development of common concepts for digital information management such as object classes, object properties, classification and object libraries to enable a unified communication
- The development, application and coordination of neutral data structure and data formats in data models, such as the Industry Foundation Classes (IFC), to enable a clear and consistent information exchange between systems and participants
- The development of unified process rules for information delivery, so-called Information Delivery Specifications that serve as a common working methodology for all participants, such as form of contract, BIM guidelines and Information Delivery Manuals (IDM)

The standardization efforts on BIM are a slowly-progressing, time-consuming and complex process with many organisations involved. The development of the IFD standard, for example, has been an ongoing process since the initial set up of the so-called "International Alliance for Interoperability" in 1994, which is now buildingSMART (Borrmann et al., 2018; Eastman et al., 2011, p. 72; Howard and Björk, 2008). The Industry Foundation Classes (IFC) is a neutral and open international standard for the exchange of BIM information between systems which is not under control by any vendor (Eastman et al., 2011, p. 73). Similar to recent standardization initiatives from the ICT domain, at its beginning, the development of IFC had been advanced by only a small circle of participants (Howard and Björk, 2008). Although the BIM standardization efforts have resulted in the first launch of IFC 1.0 already in 1997, this standard is still in an early stage of development and not widely used in practice (Golabchi and Kamat, 2013; Howard and Björk, 2008). AEC practitioners believe in standards and nominally support their use, but avoid adopting them, since the current BIM standards are considered too complex, not well marketed and incomplete and need to be improved to fit industry procedures better (Howard and Björk, 2008). Although IFC is meanwhile integrated

[2] Please see http://bit.ly/2DulJI8 for a complete list of all search phrases applied for the systematic literature review.

into > 160 software products, it is acknowledged that further optimisation efforts are needed to improve the quality and reliability of IFC data (Borrmann et al., 2018). For example, the loss of data during the information exchange process, even within one and the same BIM software, is among the major reasons for the limited use of IFC (Borrmann et al., 2018; Golabchi and Kamat, 2013). Overall, it can be stated that despite 18 years of standardization efforts, the developments of BIM standards remain an ongoing process which is considered decisive for a widespread acceptance of BIM (Howard and Björk, 2008).

The results of our study show that *lack of expertise (P2), lack of skilled personnel (P3)* as well as *lack of training (P4)* are among the major barriers that affect the people dimension of the socio-technical system. On closer investigating it becomes clear that their causes are rooted in the specific characteristics and structural nature of the construction industry. Explanations for the causes can be found in the *resource based view of the firm* (RBV), which posits that firms possess resources or capabilities enabling them to achieve sustainable competitive advantage (Barney, 2001). In a similar fashion, the *framework of resource constraints in small businesses* (Welsh and White, 1981) puts emphasis on the resource-based view of the firm by focusing on resource poverty as a distinguishing characteristic of small businesses. It must be mentioned here that according to the EBC's annual report (European Builders Confederation, 2017), 99.9% of all European construction enterprises are SMEs,[3] 96.9% of which employ < 20 people. In an effort to investigate the major impact factors of IS implementation success in small businesses, Thong (2001) argues that companies should particularly concentrate on dismantling constraints concerning technical expertise, finance and time. Grounded in the above mentioned resource-based view of the firm, the framework of resource constraints in small businesses (Welsh and White, 1981) as well as Attewell's *knowledge barrier theory* (1992), Thong (2001) examines the resource barriers in 114 small businesses with respect to their impact on the IS implementation success. The empirical results reveal that *lack of expertise and trainings* is the most significant barrier to IS adoption in small businesses.

Arendt (2008) as well concludes that the lack of knowledge, education and skills constitutes the major reason for the low level of ICT adoption among SMEs, and thus recommends strong efforts targeting skills development. Another research based on multiple in-depth case studies among 12 Portuguese SMEs echoes the results: Caldeira and Ward (2003) argue that the right mix of competences and knowledge among employees along with management support constitute the major success factors for the adoption of IS/IT. The repeatedly objected lack of expertise is due to the fact that small businesses employ generalists rather than specialists, which again is due to the prevailing limited career paths in this area (Thong, 2001). In order nevertheless to support implementation processes, small businesses must make use of external expertise by engaging consultants and IT vendors and provide training programs for employees (Thong, 2001). This is also a common suggestion from BIM literature to encounter the lack of expertise (Alhumayn et al., 2017; Ezeokoli et al., 2016).

Further important barriers that can be explained by the *resource based view of the firm* (RBV) are *lack of investment capital (TA3)* and perceived *time-consuming adoption (TE4)*. Compared to larger companies, limited financial resources prevent small businesses from extensive investments in IS and IT. However, the aim should be to allocate sufficient funds for well-tested solutions to better fulfil business requirements (Caldeira and Ward, 2003; Thong, 2001). The problem of time constraints is concerned with the limited time available for adoption activities, which can be overcome when the necessary employee resources can be dedicated to the implementation process. Also, user involvement is considered to have a positive impact on IS implementations, since incorporating employees' suggestions and requirements can significantly reduce the subsequent resistance towards the new IT. Apart from the mentioned constraints, small businesses are characterised by a highly centralized structure. Instead of multiple bureaucratic procedures as well as interpersonal and political relations, as is the case in larger organisations, the CEO, who is mostly the owner of the small firm, decides on the corporate strategy (Caldeira and Ward, 2003; Thong, 2001). Furthermore, decisions are taken more intuitively, processes are less standardised and business strategies are not necessarily scheduled for a longer term, which results in a lower organisational inertia in small businesses.

However, the lack of expertise does not only concern SMEs. In their comparative case study covering 13 industrial firms implementing an ERP system, Robey and Boudreau (1999) state that all surveyed firms face two kinds of knowledge barriers: (1) implementation and configuration of the new system and (2) assimilation of the new work processes. In order to overcome the first barrier, the firms form core teams consisting of carefully selected, motivated and empowered employees who actively promote the change and facilitate transfer and distribution of knowledge. Besides, external consultants are considered useful as intermediaries and source of external knowledge. However, in order to avoid a too strong dependence on external consultants and allow for an appropriate settling in, the external knowledge should be introduced to the organisation in due course (Robey and Boudreau, 1999). Barriers associated with the assimilation of new processes can be overcome by means of formal trainings that do not only focus on the new software but also help to master associated process changes. In this way, employees get a broader conceptual understanding of the system including the knowledge about the new business processes (Robey and Boudreau, 1999). A meta-analysis conducted by Sharma and Yetton (2007) focused on examining the impact of formal trainings on the implementation success of new IS. The empirical results indicate that, in order to avoid under- and over-investment, training programs should for one thing be tailored to the technical complexity of the IS project and also account for task interdependency (Sharma and Yetton, 2007).

Previous BIM research from the construction domain even recommended to integrate the development of BIM and collaborative skills into the curriculum of the universities (Abubakar et al., 2014; Alhumayn et al., 2017; Anuar and Abidin, 2015; Chan, 2014; Ezeokoli et al., 2016; Memon et al., 2014). Furthermore, the provision of research grants to foster research and development projects (R&D) (Zahrizan et al., 2014) as well as professional development programs for practitioners are considered indispensable (Chan, 2014; Ezeokoli et al., 2016; Memon et al., 2014).

5.2. People dimension

As is evident from the empirical results of our meta-analysis, *resistance to change (P1)* significantly hampers BIM adoption. In IS literature, resistance is a normal but complex behaviour of individuals and groups towards the uncertainty and perceived negative consequences (e.g., loss of status quo) associated to change. The desire for continuity combined with the individual's inertia and fear of job or status loss can result in diverse forms of resistance to the implementation of IT and IS (Hirschheim and Newman, 1988). As the process of IS adoption is characterised by potential stakeholder conflicts and resistance, technical-rational approaches are inadequate to ensure success. The process of technology adoption must rather be regarded as political process (Ngwenyama and Nielsen, 2014).

Resistance to change has been subject in several investigations from the IS field over the past decades. One notable example is Markus and Robey's four-level framework (Markus and Robey, 1983) to explain the resistance of organisational participants towards changes caused by implementations of new IT/IS based on the four levels of analysis: user, organisational structure, political power and environment. The political power presumes that changes caused by the implementation of new IT/IS are expected to affect the present distribution of power, which in turn

[3] The definition for small and medium-sized enterprises (SMEs) is provided in the EU recommendation 2003/361.

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causes resistance among those who fear to lose power. Thus, it is a necessary condition for a smooth implementation that the presumed and actual distribution of power are coherent (Markus, 1983; Markus and Robey, 1983). Pliskin et al. (1993) expand the above framework by cultural aspects and examine the implementation of an Employee Evaluation System (EES) at a chemical company. They argue that the level of resistance is also affected by the coherence between the presumed and actual organisational culture within the implementing organisation. The major dimensions of organisational culture include, among others, the innovation and action orientation, the willingness to take risks, the autonomy in decision making and performance or reward orientation (Pliskin et al., 1993). Another definition of organisational culture is offered by Hurley and Hult (1998), who propose learning and development, participative decision-making, support and collaboration, power sharing as well as communication and toleration for conflicts and risk as the dimensions of organisational culture. Based on the open systems approach, Martins and Terblanche (2003) identify similar determinants of organisational culture that can affect creativity and innovation within organisations, namely: strategy, support, mechanism and behaviour that encourages innovation and open communication. In total, organisational culture is generally considered to affect the extent to which innovations are encouraged, supported and implemented (Martins and Terblanche, 2003; Pliskin et al., 1993). It requires the right conditions to support creativity and innovation, which is why organisations should take proper actions to intentionally influence their values, norms and beliefs (Martins and Terblanche, 2003).

Thus, there are several ways to create an organisational culture that enhances the success of IT adoptions. First, it is recommended to foster creativity by learning and development. Second, an organisational culture that is characterised by a high tolerance for conflicts and risks as well as a high degree of support, collaboration and cross-functional communication is conducive for adoption success, since fears and uncertainties are reduced and self-confidence is enhanced (Ke and Wei, 2008). Equally decisive are power-sharing and participative decision-making, which enhances employees' acceptance, their active involvement and commitment to the new IT by increasing "*their perceived freedom to act and innovate*" (Ke and Wei, 2008). Further, companies that seek to minimise resistance should ensure coherence between the presumed characteristics of the new IT/IS and the actual characteristics prevailing in the organisation at the different analysis levels. In other words, the new IT/IS must either be adjusted to the organisational culture, or the organisational culture must be changed to facilitate the envisaged implementation (Ke and Wei, 2008; Pliskin et al., 1993). In the latter case, it is recommended to carefully monitor the change process in order to prevent resistance (Pliskin et al., 1993).

According to Ke and Wei (2008), transformational leadership constitutes another way to successfully manage IT-induced changes by enabling motivation, trust and commitment as well as a closer relationship between the transformational leaders (management) and the followers (employees). To overcome peoples' resistance, it is thus necessary to change their attitudes and perceptions towards the new IT by giving them a deeper understanding of the associated benefits. Besides, a timely involvement of individuals in the decision making and/or development process ensures user participation and commitment (Hirschheim and Newman, 1988). Thus, managements are recommended to create a strategic vision, explain the rationale behind the new IT and transparently promote costs and benefits in order to convey the new IT's importance (Ke and Wei, 2008). This again underlines the imperative nature of management support during implementation processes.

Although not immediately obvious, the *lack of management support (P6)* is proven to be a major cause for resistance (Hirschheim and Newman, 1988). Consistent with these findings from IS literature, the fundamental role of management's support is also acknowledged in BIM studies (Zahrizan et al., 2014). Hence, resolving the problems associated with this barrier can facilitate IT/IS adoptions. According to Rizzuto and Reeves (2007), the lack of management involvement is the most cited cause for failures of adoptions of technological innovations. As managements have far-reaching influences and competences as well as persuasive power, their support in IS implementation processes is more than symbolic (Caldeira and Ward, 2003; Sharma and Yetton, 2003). By devoting additional resources, the outcome of the implementation can be even more successful (Rizzuto and Reeves, 2007). As Rizzuto and Reeves (2007) further claim that the manner in which managements engage employees throughout an implementation project significantly influences their attitudes and perceptions towards the new technology, and thus the project's overall success, they recommended to actively involve staff from all organisational units instead of establishing "top-down" approaches. Further, managements should lead by example and actively foster an organisational culture of power sharing, conflict tolerance and cross-functional communication (Ke and Wei, 2008). The interdependencies of the barriers *resistance to change (P1)* and *lack of management support (P6)* become more obvious in the work of Ngwenyama and Nielsen (2014).

By viewing political behaviour in organisations as a central feature of IS adoption from the perspective of *organisational influencing theory* (Markus, 1983; Pfeffer, 1992), Ngwenyama and Nielsen (2014) demonstrate how organisations, that face unfavourable conditions for a successful IS/IT implementation, can overcome these. Their longitudinal study addresses a traditional software company that envisages the implementation of software process improvement (SPI), yet faces several constraints: The limited political power due to the lack of formal authority within the organisation, the lack of management support as well as the reputational damage resulting from a prior project failure bother the company. To counter these circumstances, Ngwenyama and Nielsen (2014) propose a well-designed and coordinated set of organisation influence processes (OIP) consisting of upward, downward and lateral influence processes and tactics. For example, in order to overcome the lack of formal authority, downward influence processes and soft tactics (consultations, education, rational persuasion and rewards) should be deployed to increase the motivation and commitment of future users. Then again, top management support could be enhanced by upward influence processes e.g. through intermediaries with formal authority over the top management. Additionally, lateral influence processes can yield support of other stakeholders who have direct authority over the target group.

From the results shown in Table 5 it can be seen that several barriers that affect the structure dimension of the socio-technical system are concerned with the *lack of awareness about BIM (S3)* and the *lack of demand (S2)*. Besides, it is claimed that there is a *lack of necessity (S5)* to use BIM and that *BIM is not widespread in construction (S6)*. These barriers reveal that construction companies seem to be satisfied with the status quo and thus do not see the need for adopting BIM. In order to understand the mechanisms that influence the intention of organisations to adopt new technologies, it is helpful to refer to the *Push-pull theory* originating from the engineering/R&D literature (Zmud, 1984). According to the push-pull theory as adapted from Zmud (1984), the adoption of a new technology may be induced by the organisation's pressure to change due to organisational needs or performance gaps (need-pull), by the recognition of technological innovations (technology-push) or the motivating forces of both (Chau and Tam, 2000).

By examining the key factors for adoption decisions of complex organisational technologies such as open systems based on the Push-Pull concept, Chau and Tam (2000) conclude with several interesting findings. From the need-pull perspective, their results reveal that the willingness to adopt new IS depends on how dissatisfied the companies are with the existing computing systems. The availability of sufficient IT resources capable of systematically evaluating the advantageousness of technologies is another major influencing factor, whereas the pressure and uncertainty coming from the external market environment proved to be no driving force (Chau and Tam, 2000). From the technology-push perspective, organisations behave rather conservatively, since they tend to pay more attention to the adoption costs and associated uncertainties than to potential benefits. Hence, uncertainty and high implementation costs are further reasons for not adopting a new system such as BIM.

In line with the above, organisations from the AEC industry see no need to adopt BIM to date, since they are obviously satisfied with the existing systems. The already mentioned large proportion of SMEs within the industry as well as their numerous resource constraints (time, financial, human) hamper IS/IT adoptions further, which is detrimental to all industry participants, because a non-widespread adoption again constitutes a reason not to adopt BIM. The causes for this can be explained by the *theory of network effects or network externalities* proposed by Katz and Shapiro (1985, 1986) who emphasize that the actually realisable benefits depend on the number of other consumers of the same good in the industry network. The existence of network effects have also been confirmed by researchers from the IS field such as Zhu et al. (2006a), stating that firms tend to adopt network technologies when the level of peer adoption in the same industry is high. Despite the existing competitive pressure, AEC companies still adopt a wait-and-see attitude and rather focus on *"managing the present"* than *"preparing for the future"* (Chau and Tam, 1997, p. 18). This behaviour has also been confirmed by other researchers from the IS field, e.g. for the adoption of complex IS such as open systems (Chau and Tam, 1997, 2000).

Another barrier that can be explained in this context is the *availability of BIM (TE6)* which has been cited as a technological barrier. According to the *theory of network effects,* the availability of a good depends on customer demand (Katz and Shapiro, 1994). Thus, the availability of BIM software can be expected to improve as soon as the adoption rate increases. Apart from these theoretical considerations, it must be stated that there are already many suppliers offering a wide range of high quality BIM software, > 280 of which offer BIM software in Europe (Roland Berger, 2017), which provides the opportunity to choose BIM software already today. To enhance the availability of BIM software, vendors are also encouraged to provide free trial software (Memon et al., 2014). Thus, it is the vicious cycle of lack of necessity (S5), lack of demand (S2), lack of awareness (S3), non-widespread use (S6) and availability of BIM (TE6) that is accountable for this unanticipated low BIM adoption rate.

In order to foster the adoption of BIM, the provision of incentives is necessary for early adopters who cannot reap the whole benefits resulting from network effects. In BIM literature, there is a widespread belief that the respective governments should start awareness enhancing programs, e.g. through the establishment of BIM centres or through "awareness road shows" (Abubakar et al., 2014; Anuar and Abidin, 2015; Zahrizan et al., 2014). In view of the complex Pull-push-mechanism, such programs should inform about costs and benefits of BIM and thus allow companies to evaluate potential risks and opportunities (Zahrizan et al., 2014). Further helpful recommendations from literature include the facilitation of knowledge sharing or the implementation assistance.

Other important barriers that are caused by the people dimension are economic barriers such as *high investment costs (TA1)* and *lack of proven benefits (TA2)*. While these barriers affect the task dimension of the socio-technical system, the causes are rooted in the social behaviour of the actors in the socio-technical system. To explain this behaviour, it is one again necessary to refer to some theories from the IS domain. The decision whether or not to invest in new IT by considering costs and benefits constitutes a major task of today's company managers (Rose et al., 2004). Harrison et al. (1997) conducted a field study involving 162 small businesses from across multiple industries to examine such decision processes from the perspective of executives. Consistent with the *Theory of planned behaviour* (Ajzen, 1991), the results of this research indicate that in small firms the decisions of executives towards IT adoptions are affected by attitudes, norms and behavioural control. To be more specific, the respective attitudes of the executives depend on the expected positive or negative consequences from the IT adoption, while the norms arise from their perception of the stakeholder expectations. The behavioural control over the adoption is dependent on the perceived obstacles or facilitators to the IT adoption and the associated belief whether or not these barriers can be overcome (Harrison et al., 1997).

Another important aspect is the behaviour in risky decision making processes, which can be explained by the *Prospect theory* delivered by Kahneman and Tversky (1979). Prospect theory assumes that individuals value losses and gains differently, depending on expected changes to their reference point rather than the actual outcome. People tend to avoid risks when they perceive the current state to be positive (gain decision domain), and they tend to seek risks when they perceive the current state to be negative (loss decision domain). As an example, if one had to decide between two possible options, both offering an equal result, but for the first the potential gains and for the second the potential losses are emphasized, the decision would be made in favour of option one (Rose et al., 2004). This behaviour is grounded in cognitive biases of the individuals which, among others, lead to the so-called "*loss-aversion*". Judging from the reference point, individuals tend to perceive the pain of losses more powerful as the pleasure of gains.

According to the results of our meta-analysis, the benefits of BIM are perceived as unproven, while the costs are perceived as too high. Hence, a manager from a construction company, confronted with the high BIM investment costs and potential, but uncertain benefits might decide to reject the investment due to this perceived "*loss-aversion*". By investigating the perceived barriers to BIM adoption by questionnaire surveys, Eadie et al. (2014) find out that non-users of BIM interestingly perceive most adoption barriers as more important than BIM users, with the exception that the lack of proven benefits receives the same value in both groups. These results show that the barriers cannot solely be overcome through policies and BIM mandates, but that the provision of cost benefit analyses demonstrating the business value of BIM is required (Eadie et al., 2014).

In order to understand the background for the next human-caused BIM adoption barrier, *lack of information sharing, collaboration and trust (P5),* a brief description of the specific characteristics of the construction industry is required. Dubois and Gadde (2002) describe the structure of the construction industry as overall loosely coupled, however with tight couplings in individual projects, which renders each construction project a unique and experimental undertaking. These characteristics support the process of short-term relationships but hamper the creation of long-term connections required for a more effective collaboration and value-co creation (Dubois and Gadde, 2002). Given these considerations, each BIM construction project can be described as a temporary network or a virtual enterprise consisting of a high number of non-competing companies collaborating based on shared information and trust in order to co-create the final product (Rizal, 2010). Hence, the value chain of a construction project can be described as a process of value co-creation (Linderoth and Elbanna, 2016).

Similar to other IS such as IOIS, BIM reduces information asymmetries among partners in value networks by supporting collaboration on the basis of one shared digital building model that provides all relevant project information, as a result of which inefficiencies can be avoided. Despite this, it has been found that even in BIM-enabled projects companies continue to work in isolation instead of fully exploiting the capabilities of BIM and collaborating effectively (Merschbrock, 2012). Hence, the lack of collaboration cannot be eliminated by solely adopting BIM (Volk et al., 2014). Moreover, *lack of information sharing, collaboration and trust (P5)* is not a BIM-specific problem, but has frequently been addressed in the IS domain, e.g. in literature dealing with supply chain management or IOIS.

As trust within any multi-organisational value network is considered crucial to collaboration, it is argued that companies trusting each other are more likely to share information in order to identify and manage inefficiencies and reduce costs (Myhr and Spekman, 2005; Yigitbasioglu, 2010). However, since by providing critical information companies put themselves at risk and jeopardises their bargaining power and competitiveness in case of abuse, companies are cautious when sharing information (Yigitbasioglu, 2010).

On individual level, the *social exchange theory* plays a major role in explaining knowledge-sharing behaviour in organisational context. According to Homans (1958), social behaviour is concerned with the exchange of material and non-material goods (such as information and knowledge) between individuals. Persons engaging in such exchanges seek to maximise their benefits and minimise their costs, with the general expectation of future returns that may lead to a balance in the exchanges (Homans, 1958). A meta-analysis conducted by Liang et al. (2008) concludes that knowledge sharing is a typical social exchange behaviour. In an effort to answer the arising question of how organisations can be motivated to exchange information and enhance collaboration, Kelle and Akbulut (2005) propose that supply chain partners can be motivated by demonstrating the potential monetary benefits and savings. The quantitative analysis of the monetary value achievable through information sharing and cooperation clearly exposes that the cost-benefit ratio can be positively influenced through a coordinated policy. In order to foster knowledge sharing, incentive programs based on extrinsic rewards are recommended (monetary rewards, work assignments, job security). The creation of organisational environments characterised by social interaction and trust as well as the required IT support facilitating social relationships is equally conducive (Liang et al., 2008).

Previous research from the IS field has shown that the process of value co-creation becomes increasingly important in multi-organisational relationships (Kohli and Grover, 2008; Peppard and Rylander, 2006). It is argued that in these value networks the process of value creation cannot be viewed from the isolated perspective of a single organisation, but rather in the whole context of the network (Peppard and Rylander, 2006). As is evident from IS literature, collaboration in supply chains does not only lead to more efficient flows of goods and services but also increases competitive advantage and corporate performance by reducing costs and response time, leveraging resources, improving innovation and enhancing decision-making (Cao and Zhang, 2011; Myhr and Spekman, 2005; Yigitbasioglu, 2010). Given the synergetic effects, the overall benefits in a collaboration are expected yet to exceed the sum of individual benefits (Bensel et al., 2008; Cao and Zhang, 2011).

In order to assess the overall value of BIM adoption, it is necessary to involve all perspectives (customers, suppliers and subcontractors). BIM literature recommends relational contracts regulating the economically fair distribution of costs, risks and benefits as being an incentive that can foster collaboration (Miettinen and Paavola, 2014). However, according to IS literature, the goal of an economically fair distribution of costs, risks and benefits between the participants of such a value network is challenging. To achieve this goal for cross-company applications such as RFID, it is therefore recommended to create a situation in which all partners of the value network perceive to reap enough benefits from the collaboration to actively take part in the network (Bensel et al., 2008). Similar to knowledge sharing, the process of sharing costs, risks, and benefits among supply chain partners is based on the assumption that each participant can equitably reap their benefit from the collaboration (Bensel et al., 2008; Cao and Zhang, 2011). Generally, stakeholders who expect to receive the greatest share of the overall benefits have the highest incentive to take part in the cost and benefit sharing network. As a further consequence, this actor is expected to be willing to bear the costs or share their own benefits with other network participants until his share of the overall benefits is equal to his individual benefits (Bensel et al., 2008). In order to foster collaboration and information sharing, it is commonly recommended to transparently visualise the benefits of collaboration based on the mentioned suggestions.

5.3. Tasks dimension

When examining the cause dimension of the adoption barriers, there is no barrier that has its roots in the tasks dimension of BIM's socio-technical system. Per definition, the tasks dimension aims at fulfilling the goals, purposes and requirements of the organisations' stakeholders (Lyytinen and Newman, 2008). This finding reveals that the tasks of BIM are not among the constraints to BIM adoption.

5.4. Technology dimension

As is evident from the quantitative results presented, BIM technology is criticised for its *complexity (TE3)* and its *lack of applicability and practicability (TE5)*. Besides, the *poor quality of model information (TE7)* has also been mentioned as technological barrier, but with a RII of 0.476 (TE7) the importance of this barrier is comparatively low. Possible explanations for these barriers can be found in IS literature, where a multitude of theories to explain and understand user reactions to IT use is proposed, from which IT design requirements can be derived.

According to the *technology acceptance model* proposed by Davis (1989), perceived usefulness and perceived ease of use are the major variables that motivate users to employ IS/IT. But how can perceived usefulness and perceived ease of use be achieved? In this context, Agarwal and Karahanna (2000) propose the *cognitive absorption model* which is focused on understanding the user's holistic experiences with new software. Grounded in previous research from the cognitive and social psychology field, the model incorporates variables describing the totality of the user's experience with new software, such as focused immersion, heightened enjoyment etc. The empirical results from a field study, with students using the World Wide Web as the target innovation, show that cognitive absorption is strongly related to the behavioural intention to use. In summary, three implications arise from this work. First, it is recommended to create an organisational environment that facilitates cognitive absorption and enjoyment as well as experimentation and exploration with the new technology. Second, the technology should be visually rich and appealing, with help menus and hot keys providing the opportunity to actively and intuitively navigate and interact. Besides, game training programs are recommended to provide enjoyable learning to the users (Agarwal and Karahanna, 2000). Implementing these recommendations contributes to overcoming the technology-related barriers and to enhance the adoption and diffusion of BIM. This is due to the fact that the value of any IS and IT can only be realised when users employ the systems *"in a manner that contributes to the strategic and operational goals of the firm"* (Agarwal and Karahanna, 2000, p. 666).

In order for this to occur, Sykes et al. (2009) propose an interesting approach that is focused on the effective use of IT after being adopted. By taking a *social network perspective* (Granovetter, 1977) to the implementation of a new content management system at a multinational company in Finland, the authors find out that the knowledge barriers associated with the use of a complex information system can be overcome when employees use their informal network and mutually support each other. Hence, in order to facilitate BIM use within adopting organisations, Zahrizan et al. (2014) suggest to establish a support group that imparts its knowledge among the staff in order to "*spread the spirit of knowledge sharing*".

Insufficient infrastructure (TE2) constitutes the last barrier from the technology impact dimension. Considering the well-known *Technology-organization-environment framework* (Depietro et al., 1990), the fundamental role of the technical infrastructure at corporate level becomes evident. Being part of the TOE-framework, the external environment dimension includes the technical infrastructure necessary for the adoption of the new technology. In order to shed light on the causes of

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this barrier, it is necessary to shift the focus of the investigation from the corporate to the broader environmental level. In this context, researchers argue that the capacity for innovations depends on the respective geographical area's technological infrastructure that is capable of providing essential input factors such as technical resources and knowledge to accomplish the innovation process (Feldman and Florida, 1994). Thereby, the sources of knowledge comprise networks of firms as well as research and development efforts, which enables innovations to emerge in the respective regions (Feldman and Florida, 1994). The *model of the geography of innovation* suggested by Feldman and Florida (1994) provides empirical evidence for these assumptions by indicating that innovations rather emerge in geographical areas that offer well-developed technological infrastructures. The fundamental role that geographical factors play in innovation processes can be confirmed by investigating the data coded for the empirical analysis with respect to the country of origins of the cited studies. In line with the model of the geography of innovation, the data reveal that insufficient infrastructures have frequently been cited as barriers in developing countries such as Nigeria (Abubakar et al., 2014; Ezeokoli et al., 2016; Onungwa and Uduma-Olugu, 2017). Only one exception stems from Hongkong, where an insufficient infrastructure is claimed as one of the barriers to BIM adoption (Chan, 2014). These findings are consistent with other studies in which basic technology infrastructures play a fundamental role for e-business assimilation in developing countries (Zhu et al., 2006b).

5.5. Socio-technical causes of BIM adoption barriers

To summarise the presented findings, the barriers are grouped into the STT dimensions according to their causes including the theoretical explanations found in IS literature (cf. Table 6). Compared to Table 5, where the barriers are clustered according to their impact dimension, a completely different picture is shown when the barriers are grouped according to their cause dimension:

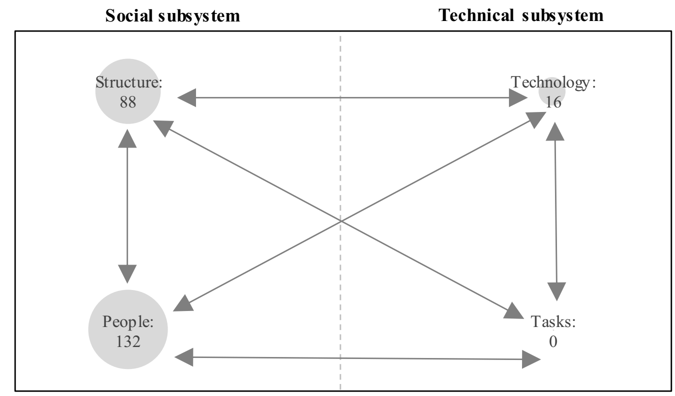

Fig. 8. Causes of BIM adoption barriers according to STT dimensions, grouped by the frequency of coded items.

Thus, in many cases the impact dimension of a barrier is not equal to its cause dimension. For example, task-related barriers such as high investment costs (P2) and lack of proven benefits (P3) are concerned with the economic goals of the organisations, but their causes are of human nature. While a slight tendency towards social issues has already been indicated by the cluster analysis according to the impact dimension of the barriers, the results presented in Table 6 show a significant shift towards social BIM barriers.

The frequency of the coded items according to their cause dimension as presented in Fig. 8 clearly confirms this shift. Compared to the

Table 6
Cluster analysis of adoption barriers according to STT cause dimensions.

Impact level		Coded items	Σw	AN	N	RII	Theoretical foundation
Structure dimension							
S1	Legal and contractual uncertainty	19	4115	5996	1156	0.686	Market failure analysis (Arrow, 1962), TOE-framework (Depietro et al., 1990),
S4	Lack of government incentives and regulation	9	2463	3190	638	0.772	Actor-network-theory (Callon, 1986)
TE1	Lack of standards and interoperability	19	4734	6604	1292	0.717	Theory of collective action (Olson, 1971)
P2	Lack of expertise	16	4781	6185	1264	0.773	Resource-based view of the firm (Barney, 2001), Knowledge barrier theory
P4	Lack of training	8	1551	2153	409	0.721	(Attewell, 1992)
P3	Lack of skilled personnel	10	2951	3743	727	0.788	
TE4	Time-consuming adoption	5	1944	2735	547	0.711	Resource-based view of the firm (Barney, 2001), Framework of resource constraints
TA3	Lack of investment capital	2	678	780	183	0.869	in small businesses (Welsh and White, 1981)
Total		88	23,217	31,386	6216	0.740	
People dimension							
P1	Resistance to change	24	5228	7144	1427	0.732	Organisational culture theory (Markus, 1983; Pliskin et al., 1993), Organisational
P6	Lack of management support	5	926	1285	257	0.721	influencing theory (Markus, 1983; Pfeffer, 1992)
S2	Lack of demand	17	5604	7530	1506	0.744	Push-pull theory (Zmud, 1984), Theory of network effects (Katz and Shapiro, 1985)
S3	Lack of awareness about BIM	11	2556	3282	643	0.779	
S5	Lack of necessity	6	1398	2110	422	0.662	
S6	Non-widespread use	3	515	723	123	0.713	
TE6	Availability of BIM	3	492	787	143	0.625	
TA1	High investment costs	33	8509	11,538	2250	0.737	Theory of Planned Behaviour (Ajzen, 1991), Prospect theory (Kahneman and
TA2	Lack of proven benefits	24	6879	9703	2027	0.709	Tversky, 1979)
P5	Lack of information sharing, collaboration and trust	6	1295	1968	372	0.658	Social exchange theory (Homans, 1958)
Total		132	33,404	46,070	9170	0.725	
Technology dimension							
TE3	Complexity of BIM	5	1516	2318	442	0.654	Technology acceptance model (Davis, 1989), Cognitive absorption model (Agarwal
TE5	Lack of applicability and practicability	4	987	1320	264	0.748	and Karahanna, 2000), Social network theory (Granovetter, 1977)
TE7	Poor quality of model information	1	76	160	32	0.476	
TE2	Insufficient infrastructure	6	686	1134	234	0.605	TOE-framework (Depietro et al., 1990), model of the geography of innovation (Feldman and Florida, 1994)
Total		16	3265	4932	972	0.662	

relatively balanced view depicted in Fig. 6, Section 4.2, it can be concluded that BIM adoption barriers are rooted primarily in the social behaviour of the actors as well as the social arrangements of the construction industry.

Our findings are consistent with the empirical evidence presented in IS literature. For example, a multidisciplinary meta-analysis conducted by Rizzuto and Reeves (2007) concludes that human-related problems are considered to be accountable for most of the failures of adoption processes, because the significance of human decisions, attitudes and behaviours are often overlooked. Similarly, Chang et al. (2008) emphasize that for IT applications requiring inter-organisational cooperation across functional areas (e.g., ERP systems) social factors have the most significant impact. Necessary social conditions for ensuring a successful implementation of complex systems such as BIM or an ERP system include, among others, a supportive social atmosphere that facilitates close cooperation and experience sharing among different participants as well as an adequate management support (Chang et al., 2008).

Consistent with these views, already previous research from the construction field concluded that in order to successfully overcome BIM barriers it is necessary to equally focus on the "softer" rather than solely on the harder, technical issues (Eadie et al., 2014).

6. Discussion

In order to investigate the barriers of BIM adoption within the global AEC industry, we have conducted a meta-analysis of 21 published studies stemming from 12 geographical areas. Compared to the only limited number of studies available in BIM literature, the collected empirical results are based on a significantly larger sample size. Drawing on the empirical results as well as the established theories from the IS research domain, this study aggregates the most important BIM adoption barriers, explains their causes and provides adequate solutions. To the best of our knowledge, our meta-analysis is among the first attempts to empirically examine the barriers to BIM adoption from a broader global perspective including theoretical founded explanations of the results.

Our analyses point to several theoretical findings that can be borrowed from IS literature. Consistent with empirical evidence from IS and BIM literature (Chang et al., 2008; Eadie et al., 2014; Rizzuto and Reeves, 2007), social barriers relating to the "people" and the "structure" dimension of the BIM socio-technical system can be mentioned as the most important barriers to a widespread adoption of BIM. On the one hand, the severe structural barriers experienced by many construction companies when aiming at introducing BIM are caused by the lack of institutional arrangements as well as several structural constraints resulting from the specific characteristics of the AEC industry. The barriers that are enrooted in the people dimension of the socio-technical system, on the other hand, are concerned with the behaviour of individuals within the organisational environment (managers, employees, stakeholders) (Lyytinen and Newman, 2008). This behaviour can manifest itself in a resistance to change, a lack of management support or a "*loss-aversion*" when making decisions towards the adoption of BIM. Compared to the social barriers, purely technical rooted adoption barriers are rather rare and, measured by their RII, even considered as less critical. Given the proven relevance, research and practice should concentrate more strongly on the social rather than the technical barriers.

6.1. Limitations

As with any research, this study has limitations that must be taken into account and give direction to future research. First, the empirical results of the meta-analysis are based on the sample of the selected studies which we have identified during the search process. However, we cannot guarantee that we have captured all relevant studies, since there may exist unpublished or published studies that we might have overlooked. For example, we have merely included studies published in English language. Thus, the results only reflect the empirical findings from English-speaking countries or research from other countries that has been published in English, while ignoring study results that are published in the native language of other researchers and practitioners. Possible extensions of this research could involve insights yielded from studies published in other languages to receive a more comprehensive and global picture about the adoption barriers of BIM. Second, grounded in our strict selection process, the number of 21 selected studies is relatively small, and as we do not cover all relevant geographical areas, the results cannot be considered representative. In our selection process, for example, we had to exclude all commercially-driven studies because they are solely based on simple multiple-choice ratings and do not provide the essential study characteristics necessary for further analysis. But despite this selection process, we are not entirely reassured whether the coded and analysed data of the selected studies satisfy the highest quality standards. Further research is needed to compare our quantitative results with those studies based on other types of data, e.g., multiple-choice ratings or qualitative findings from expert interviews.

In our meta-analysis, we applied cluster analysis to summarise the data by assigning each item to defined clusters of adoption barriers. For example, all barriers that are concerned with adoption costs are assigned to the cluster "High investment costs". However, in a few cases, there do exist overlaps in the sense that one adoption barrier could also be assigned to other clusters. The item "*Our firm believes that it takes too much organisational efforts to adopt BIM*" (Hosseini et al., 2016), for instance, could equally be assigned to the cluster "*High investment costs*" or "*Time-consuming adoption*". As in this specific case we assume that the "organisational efforts" relate to costs rather than time, we allocated this item to the cluster "*High investment costs*". Thus, while we thoroughly clustered the identified items, a slightly different picture may emerge depending on another clustering.

Another limitation is concerned with the qualitative results originating from the literature review. Given the comprehensiveness of the various research streams around the adoption of innovations in general and IT/IS in particular, a complete review of the IS literature is outside the scope of this paper. Instead, we rather focus on providing empirical evidence from the IS domain in order to explain the adoption barriers based on selected findings. This limitation provides several opportunities for future research. For one thing, the explanations suggested in this paper should be extended by further theories from the IS domain, which may lead to additional empirical evidence or more appropriate explanations for the barriers. Moreover, it might be useful to look at the social barriers through the lens of social and organisational psychology.

The second major limitation concerning the qualitative results of the literature review emerges from its applicability to BIM. The conclusions drawn in this study are based on empirical data from the BIM research field, combined with other empirical findings stemming from a wide range of previous studies from the IS/IT innovation adoption literature. Given its interdisciplinary and interorganisational nature, BIM can be considered as an Interorganisational Information System (IOIS) that facilitates information exchange and collaboration across company borders (Bosch-Sijtsema et al., 2017). However, it must be questioned whether the empirical findings from studies on the adoption of IS/IT innovations such as ERP, RFID or IOIS are applicable to BIM. As a consequence and given the unique characteristics of the construction industry as well as the specific nature of BIM, the emerging causalities and the application of findings from IS literature to the context of the construction domain must be approached with care. It is therefore recommended to further examine the findings in order to prove their validity for the specific context of BIM and the construction domain. Likewise, it might be beneficial to examine to what extent and under what circumstances causalities occur.

In addition, it makes sense to examine the mediating role of firm

Table 7
Propositions for managers, industry participants and policy makers.

#	Proposition	Barrier
	Structure dimension	
1	• Government bodies should support the diffusion of BIM by taking an active role through regulations (legal and contractual issues) and provision of incentives, e.g. promoting and funding programs and technology transfer (Moon and Bretschneider, 1997; Smith, 2000). • These actions should include promotional activities for increasing the awareness about the new technology, subsidies of R&D costs as well as the provision of the appropriate legal environment (Moon and Bretschneider, 1997). • Government regulations are a more important factor in developing than in developed countries (Zhu et al., 2006b).	S1, S4
2	• Cooperative activities are required to foster the adoption of BIM, since innovations in "complex technology systems" (such as BIM), are collective achievements of different actors like private companies and government bodies rather than of individual firms (Yoo et al., 2005).	S1, S4
3	• The development of industry-wide standards requires the participation of representatives from all industry groups to equally meet the requirement of users (construction companies, project owners, architects, sub-contractors, supplier) and vendors (Markus et al., 2006). • The diffusion of these standards can only be ensured by involving participants into the standard development process who are key to standards diffusion or are expected to have the greatest possible influence within the diffusion process (Markus et al., 2006). • Local governments should also play a vital role in overcoming these barriers by enforcing legislative BIM standards and specifications on construction projects (Chan, 2014; Newton and Chileshe, 2012).	TE1
4	• In order to overcome knowledge barriers associated with the implementation and configuration of BIM, firms should make use of core teams consisting of carefully selected, motivated and empowered employees to actively promote change and learning and to facilitate knowledge transfer and knowledge distribution (Robey and Boudreau, 1999). • Due to internal expertise constraints, SMEs should make use of external expertise by engaging consultants and IT vendors to support the implementation process as well as by providing training programs for employees (Thong, 2001). • Companies should ensure that external knowledge is transferred into the organisation in a timely manner instead of being too dependent on external consultants (Robey and Boudreau, 1999). • Formal trainings should not only focus on the BIM software itself but rather on change management and process-oriented issues in order to ensure that employees get a broader conceptual understanding of the system including the knowledge about the new business processes (Robey and Boudreau, 1999). • Training programs should be designed based on technical complexity and task interdependency in order to avoid under-investment and over-investment (Robey and Boudreau, 1999). • The integration of BIM into the curriculum of the universities is recommended in order to help students to develop BIM and collaborative skills and the provision of research grant to foster efforts towards research and developments (R&D) (Abubakar et al., 2014; Alhumayn et al., 2017; Anuar and Abidin, 2015; Chan, 2014; Ezeokoli et al., 2016; Memon et al., 2014).	P2, P3, P4, TE4, TA3
	People dimension	
5	• Organisations should take the right actions to intentionally influence their values, norms and beliefs to the extent that can avoid resistance and support creativity and innovation (Martins and Terblanche, 2003). This includes: • The creation of an organisational culture of learning and development in order to foster creativity (Ke and Wei, 2008) and an organisational culture that is characterised by a high tolerance for conflict and risk as well as a high degree of support, collaboration and cross-functional communication (Ke and Wei, 2008). • The creation of an organisational culture of power-sharing and participative decision-making can help to enhance employees' acceptance, their active involvement and commitment towards the new IT (Ke and Wei, 2008). • The IT/IS to be implemented must be adjusted to fit the organisational culture, or the organisational culture must change to facilitate the implementation of the new IT/IS (Ke and Wei, 2008; Pliskin et al., 1993). • The company's management should create a strategic vision around the new IT to actively explain the rationale for its adoption and to transparently promote its costs and benefits in order to make employees feel the need for the new IT (Ke and Wei, 2008). • In order to ensure user participation and commitment, it is recommended to actively involve staff from across all organisational units into the decision making or the development process right from the beginning instead of establishing "top-down" approaches (Hirschheim and Newman, 1988; Rizzuto and Reeves, 2007) • Under certain circumstances, it is necessary to design and implement a coordinated set of organisation influence processes (OIP) consisting of upward, downward and lateral influence processes as well as influence tactics to achieve the desired outcomes towards the adoption process (Ngwenyama and Nielsen, 2014). • The company's management can foster an organisational culture of power sharing, conflict tolerance and cross-functional communication by actively demonstrating these behaviours and by setting examples (Ke and Wei, 2008)	P1, P6
6	• The decision towards the adoption of a new IS is induced by the organisation's pressure to change due to organisational needs or performance gaps rather than the pressure and uncertainty coming from the external market environment (Chau and Tam, 2000). • In order to improve the awareness and the adoption rate of BIM, the provision of incentives is necessary for early adopters who cannot reap the whole benefits resulting from network effects (Zhu et al., 2006b). • Awareness enhancing programs that provide information on the costs and benefits of BIM adoptions are recommended in order to help companies to evaluate potential risks and opportunities (Zahrizan et al., 2014). • To enhance the availability of BIM software, software vendors are encouraged to provide free trial software to potential adopters (Memon et al., 2014).	S2, S3, S5
7	• As the economic barriers cannot be overcome by solely making policies and introducing BIM mandates, it is necessary to provide cost benefit analyses in order to overcome the "loss-aversion" of decision makers. • This can be achieved by demonstrating BIMs business value and thus convincing managers of the necessity for BIM (Eadie et al., 2014).	TA1, TA2
8	• The supply chain partners can be motivated to use new IS for information sharing, cooperation and cost optimization by demonstrating the potential savings. This can for instance be acknowledged by providing quantitative analyses of the monetary values that are achievable through information sharing, cooperation and a coordinated policy (Kelle and Akbulut, 2005). • In order to foster knowledge sharing, incentive programs based on extrinsic rewards are recommended (monetary rewards, work assignments, job security). Additionally, managers should create an organisational environment that fosters social interaction and trust as well as the required IT support in order to facilitate the creation of social relationships (Liang et al., 2008). • Furthermore, relational contracts that equitably distribute risks and rewards among the partners of the construction project serve as the necessary incentive to foster collaboration (Miettinen and Paavola, 2014)	P5

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Table 7 (*continued*)

#	Proposition	Barrier
	Technology dimension	
9	• It is recommended to create an organisational environment that facilitates cognitive absorption and enjoyment as well as experimentation and exploration with the new technologies (Agarwal and Karahanna, 2000). • The technology should be visually rich and appealing, with help menus and hot keys, which provides the users the opportunity to actively and intuitively navigate and interact. Besides, game training programs are recommended to provide enjoyable learning to the users (Agarwal and Karahanna, 2000). • Knowledge barriers associated with the use of a complex information system can be overcome when employees use their informal network and mutually support each other (Sykes et al., 2009).	TE3, TE5, TE7
10	• Since in developing countries the basic technology infrastructure plays a fundamental role for e-business assimilation (Zhu et al., 2006b), concerted action among government bodies and industry partners are required to establish a technological infrastructure that is capable of providing essential input factors to accomplish the innovation process (Feldman and Florida, 1994).	TE2

size, stakeholder role or level of expertise, etc. in order to uncover further causalities. As we have already learnt from IS research, small businesses suffer from resource constraints (Thong, 2001), whereas larger firms enjoy resource advantages but are often burdened by structural inertia due to their fragmented organisational structure (Zhu et al., 2006b). Thus, it would be interesting to find out whether larger firms suffer more from barriers resulting from change processes (e.g., redesign of business processes and organisational structures) or rather from barriers relating to expertise and finance. Besides, it would be helpful to see whether the importance of the barriers differs from the perspectives of project owners, subcontractors, designers or project managers.

6.2. Implications for practice

Our research is expected to be of value to industry practitioners as it creates a deeper understanding about the causes of the adoption barriers and thus helps to overcome these. Looking behind the scenes through the lens of IS theories and mapping the results according to the STT helps us to more transparently view the causes, problems and key findings of this research (cf. Table 7) in order to address implications for practice in terms of 10 main propositions. As previously stated, BIM constitutes an interdisciplinary and interorganisational information system that requires concerted efforts among several participants to be successful. Thus, the propositions made in this research are not only directed towards managers, individuals and groups across the AEC industry, but also towards policy makers and tertiary institutions.

The propositions can help organisations considering an adoption of BIM to evaluate the efforts that are required to overcome the adoption barriers. For companies that already made the decision towards BIM adoption, the findings of this research serve as an aid for preparing the implementation process by understanding the adoption barriers prior to reaching out for solutions. The introduction of BIM undoubtedly results in changes within organisations, including the organisational processes and cultures as well as the way people work. Furthermore, the development of appropriate strategies for overcoming adoption barriers and ensuring successful adoptions constitutes a major challenge for decision-makers. Since several barriers to BIM adoption require an active role of government bodies, the results of our study offer implications for policy makers as well.

6.3. Implications for research

Notwithstanding the limitations mentioned above, this study contributes to the IS/IT innovation adoption literature in several ways. For researchers from the construction domain and the IS field alike, it provides implications and possible pathways for future research. In this context, it is important to emphasize that more interdisciplinary research is needed that combines latest findings from the construction research field with the established body of knowledge from the IS discipline to encourage BIM research.

By analysing and synthesizing the qualitative data from our literature review, we discovered interrelations between many barriers that can be derived from empirical findings in IS literature. For example, lack of management support (P6) and lack of expertise (P2) are considered to be a major cause for resistance to change (P1) (Hirschheim and Newman, 1988). Other obvious interrelations are concerned with diverse barriers associated with the diffusion of BIM such as lack of demand (S2), lack of awareness about BIM (S3), lack of necessity (S5), its non-widespread use (S6) and availability (TE6). Based on the explanations provided in IS literature, various interrelations between these barriers become apparent. First, according to the push-pull theory as adapted from Zmud (1984), the adoption of a new technology is induced by the organisation's pressure to change due to organisational needs or performance gaps. Hence, lack of necessity (S5) is expected to result in lack of demand (S2) and lack of awareness (S3), which in turn ends up in a low level of adoption. According to the theory of network effects (Katz and Shapiro, 1994), this non-widespread adoption of BIM is in turn expected to negatively affect the availability of BIM software.

Apart from these examples, there are several similar interrelations that need further investigation. Given these findings, it might be beneficial to examine which barriers are interrelating and to what extent a certain barrier can affect another barrier. Returning to the examples, it would be also helpful for companies to know which barrier should be given the most attention: Is it helpful to focus on providing trainings in order to overcome the lack of expertise (P2), or is it necessary to focus on providing more management support (P6)? These findings are imperative for a complete picture of the adoption barriers and a more conceptual understanding through the lens of systems theory. On this basis, the empirical findings can be applied to simulate and understand the dynamics of the barriers with respect to external input factors. For instance, it is possible to examine to which extent governmental incentives or investments in trainings can influence the adoption success.

Another promising avenue for future research is to examine the similarities and differences between the adoption barriers to BIM and one of the most popular concepts within the AEC industry of the past decades: Lean Design and Construction. Similar to BIM, Lean Design and Construction is aimed at achieving substantial benefits such as the reduction of costs, risks and delays, more efficient buildings, and a higher user satisfaction (Forbes and Ahmed, 2010, p. 57; Sacks et al., 2010). The reduction of waste as well as continuous improvements are further central aspects of Lean Design and Construction. While the emphasis of BIM is put on the introduction and application of an innovative information technology, Lean Design and Construction is a conceptual approach with a multitude of principles to be deployed within the entire project lifecycle (Sacks et al., 2010). As with BIM, the Lean concept suffers from several barriers that prevent its widespread adoption (Pheng and Shang, 2014; Sarhan and Fox, 2013). The lean concept is a well-researched area in construction, offering a well-founded base of literature, that researchers can elaborate upon to identify possible solutions to unsolved problems concerning the adoption barriers.

Given the relevance of BIM for many organisations from the AEC

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industry, there is a clear need to further investigate the adoption barriers of BIM to move this topic towards new frontiers. Therefore, we suggested several implications that arise from the limitations of this study as well as interesting directions that future research needs to follow.

7. Conclusion

Drawing on STT as well as the established body of knowledge from the IS research domain, we examine the barriers to BIM adoption according to their impact level as well as their cause level. The findings reveal that in many cases the impact dimension of an adoption barrier is not equal to its cause dimension. While a tendency towards social barriers is indicated when considering the impact dimension of the barriers, a significant shift towards the social barriers of BIM is apparent when regarding their causes. In general, it can be concluded that the barriers to BIM adoption are primarily rooted in the social behaviour of the actors as well as the social arrangements of the construction industry rather than technical issues. In order for the industry-wide adoption of BIM to be successful, concerted efforts are required from various individuals and industry groups, such as construction companies, designers, project owners, BIM vendors and governmental bodies to overcome the human and structural barriers. Against this background, our research provides researchers and industry practitioners with a set of propositions that can be taken into account when making decisions towards BIM adoption. These propositions should serve as an aid for gaining an enhanced understanding for the adoption barriers prior to developing coping strategies.

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