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EVALUATING AUGMENTED REALITY APPLICATIONS IN CONSTRUCTION – A COST-BENEFIT ASSESSMENT FRAMEWORK BASED ON VOFI

Thuy Oesterreich
Osnabrück University, Osnabrück, Germany, toesterreich@uni-osnabrueck.de

Frank Teuteberg
Osnabrück University, Osnabrück, Germany, frank.teuteberg@uni-osnabrueck.de

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Research paper

Oesterreich, Thuy Duong, Osnabrück University, Osnabrück, Germany, toesterreich@uni-osnabrueck.de

Teuteberg, Frank, Osnabrück University, Osnabrück, Germany, frank.teuteberg@uni-osnabrueck.de

Abstract

Industry 4.0 application scenarios, based on the use of Augmented Reality (AR) in combination with wearable devices like Smart Glasses or Head-Mounted Displays (HMD), offer construction companies several opportunities to better deal with the complexity of the construction environment. Despite the given maturity of AR technology, tools or methods to estimate the costs and benefits associated with its adoption have not been provided to date. In general, high implementation costs and unclear benefits of this technology are considered as barriers to its widespread adoption. Therefore, the primary aim of this paper is to develop an assessment framework for evaluating costs and benefits of information systems (IS) investments based on an AR-based application scenario in the construction domain. By the same token, we intend to demonstrate how a traditional cost-benefit analysis (CBA) can be applied more effectively to assist in the decision-making process. The assessment framework is developed by means of a systematic literature review and evaluated by means of expert interviews as well as a simulation using the appraisal method Visualisation of Financial Implications (VoFI). Additionally, risk considerations are made by conducting a sensitivity analysis and a probability risk analysis.

Keywords: Cost-Benefit Analysis, Assessment Framework, VoFI, Augmented Reality, Simulation.

1 Introduction

Nowadays, digitisation technologies play an important role in the manufacturing industries. As requirements toward functionality, customisation and delivery have steadily increased, products and production processes are getting more and more complex. Digitisation technologies in the context of Industry 4.0 have been promoted to reduce this complexity and to optimise the production processes (Kagermann et al., 2013). Among the central concepts of Industry 4.0, mobile assistive systems based on Augmented Reality (AR) technology and wearable devices like Head Mounted Displays (HMD) and Smart Glasses have been proposed for multiple purposes, e.g. for training and education or for improving information sharing and communication (Bauernhansl et al., 2014; Spath et al., 2013, p. 61). Especially for the construction industry, AR-based assistive systems offer great possibilities to overcome several challenges resulting from the specific characteristics of its hazardous and complex manufacturing environment. For example, the use of AR in combination with Smart Glasses can help to improve the on-site safety for workers by enabling instruction manuals or remote support in hands-free mode (Ubimax GmbH, 2016). Beyond this, the technology may assist in enhancing collaboration and improving customer relationship (Trimble Buildings, 2015). Despite the named benefits, the use of AR is not widespread in construction.

According to recent surveys, high implementation costs and unclear benefits have been mentioned by German companies from the manufacturing industries as barriers to Industry 4.0 adoption (Kelkar et al., 2014, p. 6; Lichtblau et al., 2015, p. 57). Thus, the development of methods for estimating costs and benefits can help companies to evaluate the potential effectiveness of the investments. In general, the evaluation of information systems (IS) investments at the proposal stage is considered as a problem area in both research and practice (Murphy and Simon, 2002; Renkema and Berghout, 1997; Schryen, 2010). Hence, the primary aim of this paper is to develop an assessment framework for evaluating costs and benefits of IS investments based on an AR-based application scenario from the construction domain. For this purpose, we intend to answer the following research questions:

1. *What are the costs and benefits associated with the use of AR in combination with HMD or Smart Glasses in the construction domain?*
2. *How can these costs and particularly the tangible and intangible benefits be estimated by means of a cost-benefit analysis (CBA) in an adequate manner?*

Adding to the body of knowledge, this approach should be a first step for assessing and understanding the economic effects of investments in AR technologies in the context of Industry 4.0. Besides, the cost-benefit framework can be used as a helpful tool for decision support.

The remainder of this paper is structured as follows. In section 2, the AR application scenario is presented including a brief overview of the state of the art. Subsequently, we introduce the research design of this paper in section 3. In section 4, the assessment framework is designed based on the results of our systematic literature review. Section 5 is dedicated to the development of the CBA framework as well as the simulation of the model by means of the method Visualisation of Financial Implications (VoFI) in an Excel tool. Finally, the results are discussed in section 6, followed by the conclusion in section 7.

2 Augmented Reality Applications in Construction

The field of Augmented and Virtual Reality has been introduced by several researchers in the second half of the 20th century (Caudell and Mizell, 1992; Sutherland, 1968). According to Milgram et al. (1995), Augmented Reality (AR) is a part of the reality-virtuality continuum, in which the user’s natural experiences are augmented by means of simulated cues. Virtual Reality (VR), on the contrary, enables the user to totally immerse in a completely synthetic world. The term Mixed Reality (MR) merges both concepts into a mixed environment and has often been used as an interchangeable term for AR (Dunston and Wang, 2005). In this paper we refer to the more restricted definition of AR which additionally includes the use of a transparent head-mounted display (HMD) allowing the participant to capture a clear view of the real world (Milgram et al., 1995, p. 283).

In recent years, AR has become an area of growing interest for both researchers and practitioners, since the level of maturity of the technology has increased rapidly regarding the plethora of available solutions. The application of AR-based assistive systems in construction, e.g. as a stand-alone solution or in combination with the digital planning method Building Information Modelling (BIM), enables all project members to collaborate in an efficient way throughout the construction process (Dunston and Wang, 2005; Jiao et al., 2013; Wang and Love, 2012).

In practice, the field of AR is still at the formative stage, as applications for the use in construction are still under development. For example, the MR application presented by Trimble and Microsoft uses the HoloLens and 3D modelling technology to enable users to interact with 3D holograms blended into the real world (Trimble Buildings, 2015). Several AR-based solutions are already available, offering a multitude of applications for the use with mobile devices or wearable computing to enhance safety on construction sites (Jones, 2014). For example, the hard hat “Daqri Smart Helmet” has been proposed to aid construction workers by displaying 3D visual overlays in the wearer’s field of vision (“DAQRI Smart Helmet”, 2016). Other applications based on the use of Google Smart Glasses have been offered for enabling instruction manuals or remote support in hands-free mode (Ubimax GmbH, 2016). Given the maturity and availability of AR technology, the adoption of AR applications to support the construction process is a realistic application scenario within the context of Industry 4.0.

3 Cost-Benefit Analysis (CBA) for IS Investments

The evaluation of IS investments at the proposal stage has been described as a problem area in both research and practice (Renkema and Berghout, 1997; Sassone, 1988). However, cost-benefit analysis is considered as an essential influencing factor for the pace of business automation, since it can support the decision-making process by guiding managers to more profitable decisions about the IS investment (King and Schrems, 1978; Sassone, 1988). In this paper, our primary aim lies on the ex-ante view of the IS investment at the proposal stage where the investment decision has to be made. To build our work on a solid basis, we draw our research design on 4 major steps in performing a cost-benefit analysis based on Sassone and Schaffer (1978).

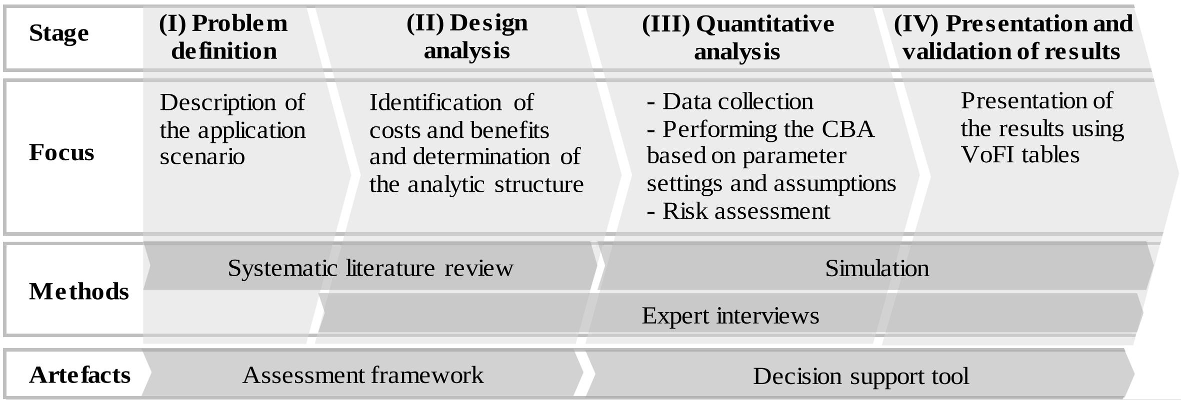

Figure 1. Research design based on Sassone and Schaffer (1978).

As shown in Figure 1, the starting point of our investigation is the definition of the problem, which is carried out in sections 1 and 2. In the second step, a systematic literature review is conducted to design the analytic structure of the CBA. To do so, we follow the guidelines on conducting IS literature reviews provided by vom Brocke (2009) and Webster and Watson (2002). Our literature search is carried out in 5 interdisciplinary databases *EbscoHost, Web of Knowledge, ScienceDirect, Ingentaconnect and SpringerLink* by applying the search terms *"Construction Industry" AND ("Augmented Reality" OR "Smart Glasses" OR "Head Mounted Display")*. Where possible, we restrict our search to focus on a match in title, keywords, abstract and subject terms of each database. Furthermore, we broaden our literature search by performing a Google search with the same keywords in order to cover more practical publications (e.g. magazines, market analyses, product brochures). Additionally, a forward and backward search to all relevant papers is conducted to extend the literature basis. Relevant articles of our literature search should address issues about costs and benefits of AR applications for the use with HMD or Smart Glasses. Finally, 30 publications of 472 overall hits are selected to be further investigated within the design analysis section (section 4.1 and 4.2).

The assessment framework, comprising all costs and benefits as well as a mathematical model for the appraisal of the investment, serves as a basis for the last steps of the quantitative analysis as well as result presentation and validation. As models tend to be complex and often are based on constraining assumptions, simulations can help to study the model and its validity (Law and Kelton, 1991). In this paper, Excel-based simulations are applied to test the mathematical model of our assessment framework by following the recommended steps in a simulation study delivered by Law and Kelton (1991, p. 107). The quantitative analysis of the assessment framework is carried out by means of the capital budgeting method VoFI (Grob, 1989) including a risk assessment step. Finally, expert interviews are conducted to evaluate the practicability of the artefacts (Cleven et al., 2009; Sonnenberg and Brocke, 2011).

4 Designing the Assessment Framework

4.1 Cost taxonomy

Already in 2005, the lack of cost implications for AR and MR systems in construction has been criticised by Dunston and Wang (2005). Even today, despite the fact that the technology of AR and MR is meanwhile at a high maturity level, the situation is practically unchanged. Although we have thoroughly analysed the identified publications of our systematic literature review, we cannot find any contribution that provides cost implications for AR applications in construction.

Given these circumstances, we draw on the body of knowledge by relying on the cost taxonomies presented in IS literature. In order to take into consideration the wide range of social and organisational costs associated with the investment scenario, we decide to apply the cost taxonomies suggested by Irani et al. (2006), King and Schrems (1978) as well as the work of Friedrich (2004) about cost implications of AR systems. To do so, we merge these taxonomies to a modified cost taxonomy in Table 1 by adding specific information about the AR-based application scenario (e.g. concerning hardware specifications like Smart Glasses and sensors) and excluding unneeded cost elements (e.g. environmental costs and costs due to knowledge reduction which might occur as a result of outsourcing decisions). Additionally, we assign all relevant costs to 3 cost categories. Moreover, the time dimension of each cost element has been added to the list. The time dimension t=0 refers to the period of adoption, while t>0 represents the periods after the implementation.

		Reference			Timeline	
Cost category		Irani et al. (2006)	Friedrich (2004)	King and Schrems (1978)	**t = 0**	**t > 0**
Technology-related costs						
Initial costs	Hardware equipment costs (HMD, Smart Glasses, sensors)	x	x	x		
	Software costs (Apps, contents etc.)	x	x	x		
	Cost of software and data modifications	x		x		
	Equipment and software installation costs	x	x	x		
	Consulting costs	x	x	x		
	Infrastructure costs (Workplace design, connectivity)	x	x	x		
Ongoing costs	Hardware maintenance costs	x	x	x		
	Software maintenance costs	x	x	x		
	Support costs	x	x			
	Upgrade costs	x	x			
	Rental costs (Licenses, broadband connectivity, etc.)	x		x		
Personnel costs						
	Cost for training user personnel in application use	x	x	x		
	Cost of management and staff dealing with procurement	x		x		
	Cost of management and staff required to start-up activities	x		x		
	Cost of management, administration and operation activities	x	x	x		
	Cost of in-house application development	x	x	x		
	Changes in salaries	x				
Organisational costs						
	Costs of business process restructuring (BPR)	x				
	Costs for change management	x				
	Cost of disruption to the rest of the organisation	x		x		
	Overheads	x		x		

Table 1. Consolidated cost taxonomy for the AR application scenario.

The first cost category in Table 1 refers to technology-related costs comprising all kinds of initial and ongoing costs required for the technical implementation and application of the new system, such like hardware equipment costs, software costs, modification costs, installation costs or system maintenance costs. As mentioned earlier, the market of wearable devices and apps for AR solutions is extraordinarily dynamic, with expected growth rates of 141% in the next four years (Wearable Tech, 2016). Although a long-term development of hardware costs for wearable devices cannot be foreseen at this point in time, the price histories of other innovative technologies usually show a decline in price with the market entry by first competitors (Rauschnabel et al., 2015). Due to the dynamic changes in the market of AR technology and wearable devices, the provision of an average amount for the application scenario does not make sense at this point. To quantify technology-related costs for the AR application scenario, it is necessary to conduct a market analysis for the identification and selection of the appropriate hardware and software. This step should be carried out thoroughly with respect to the requirements and needs of the corporate environment where the new technology is implemented.

The second cost category consists of personnel costs resulting from the initial implementation and ongoing use of the new technology. Costs for management and staff, costs for user training as well as costs for the in-house application development are possible examples. While expressing costs in monetary terms is simple when a competitive market price for this cost exists, in-house expenditures are difficult to calculate due to the non-availability of market prices (Hares and Royle, 1994). The quantification of in-house expenditures requires a further step of measurement. For example, the costs of management and staff dealing with procurement are quantifiable based on estimations of the time needed for this task as well as the costs per time unit for each employee involved. Organisational costs like costs for Business Process Reengineering, change management or disruption are summarised in the third cost category. According to Irani et al. (2006), organisational costs are unavoidable costs which occur as an indirect consequence due to the adoption of the new technology. For example, resistance to change is a main barrier to an effective use of the new system, which in turn results in a decrease in productivity (Irani et al., 2006). Due to their intangible nature, Irani et al. (2006) argue that social and organisational costs cannot be incorporated within traditional economic appraisal techniques, but rather with other appraisal techniques such as the balanced score card. However, the use of the balanced scorecard does not result in a financial measure and thus cannot be incorporated into a CBA for decision-making.

In general, there exist four cost accounting problems which have to be taken into account (King and Schrems, 1978): Double counting, omission of costs, hidden costs and spillovers. The danger of double counting often occurs in complex analyses where the same cost might be included in different positions, while omitting significant costs refers to the oversight of costs. Hidden costs can occur due to the fact that the share of overhead costs might be too small, or the inclusion of personnel or other resources might be incomplete. Increases in staff salaries due to enhanced job requirements (Irani et al., 2006) are possible examples of hidden costs. Another cost-accounting problem are spillovers, which lead to secondary financial effects (King and Schrems, 1978).

4.2 Benefit framework

Due to the plethora of different kinds of intangible benefits, the quantification of benefits is considered as the biggest obstacle to a CBA of IS investments. In particular, measurement problems arise from the quantification of intangible benefits like *"improved decision-making"* or *"enhanced customer-relationship",* because it is difficult to assign values to these factors. Hence, these benefits must be broken down into sub-benefits to make them measurable (King and Schrems, 1978). For this purpose, Murphy and Simon (2002) apply the following set of steps adapting from Hares and Royle (1994) in Figure 2.

Beginning with the first step, which can be carried out by identifying critical success factors or by creating a checklist of intangibles, we analyse the results of our systematic literature review based on the 30 publications identified during the search process. In contrast to the apparent lack of cost implications, benefits are mentioned frequently in all publications. Hence, the identification of both intangible and tangible benefits for the AR-based application scenario to create a checklist is selected as the starting point within the quantification process.

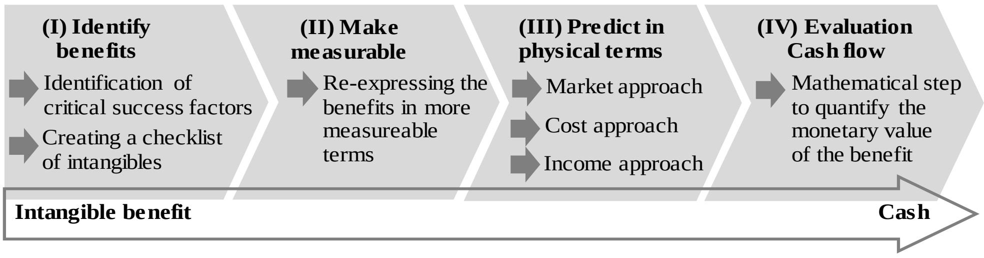

Figure 2. Quantification technique for intangible benefits adapted from Hares and Royle (1994).

In general, AR technology can be applied at the stages of planning and design, construction, maintenance management and demolition within the construction value chain (Choi, 2009). Based on 5 main application areas within these stages, the most frequently mentioned benefits are summarised in our benefit framework (Table 2). The first main application area *"visualisation and simulation"* offers all project participants the opportunity to visually explore the 3D model of a building for a better understanding of design and construction and thus to improve customer relationship, reduce complexity and enhance quality by avoiding rework and defects (Agarwal, 2016; Wang et al., 2013).

Measure		**Timeline**	
Benefit	**Measurable term**	**t = 1**	**t > 1**
Operational benefits			
Reducing complexity (Schnabel, 2009; Wang et al., 2013)	Time savings		
Improving efficiency (Agarwal, 2016; Algohary, 2015; Kamat et al., 2010; Wang and Love, 2012)	Time savings		
Reducing the amount of paper (Friedman, 2015)	Cost savings		
Tactical benefits			
Improving quality (Agarwal, 2016; Kamat et al., 2010; Wang et al., 2013)	Cost savings		
Improving on-time and on-budget-delivery (Wang et al., 2013)	Cost savings		
Reducing physical and mental workload for employees (Dong et al., 2013)	Cost savings		
Enhancing safety (Algohary, 2015; Friedman, 2015; Thiel and Thiel, 2014)	Cost savings		
Increasing self-satisfaction (Wang and Dunston, 2013)	Cost savings		
Improving decision-making (Ervin, 2016; Friedman, 2015; Wang et al., 2013)	Time savings		
Improving customer relationship (Agarwal, 2016; Wang et al., 2013)	Sales increase		
Strategic benefits			
Improving growth and success by creating new business models	Sales increase		
Improving market share and market position	Sales increase		
Improving corporate image	Sales increase		

Table 2. Benefit framework.

Within the second application area, the combined use of AR and a HMD can help to optimise project planning and coordination by identifying design errors and schedule conflicts. Furthermore, it provides support by means of an efficient progress monitoring and allows for an improved quality, improved on-time and on-budget delivery (Agarwal, 2016; Algohary, 2015; Wang, 2009). Communication and collaboration is another central application area of AR where the HMD can be used as a wearable device to collaborate over distance, e.g. for remote instructions and information sharing (Algohary, 2015; Friedman, 2015; Wang et al., 2013). The most central application area of AR comprises a wide range of tasks to access, evaluate and collect real-time and context-sensitive information in hands-free mode with the purpose of enhancing safety, reducing paperwork and workload for employees, improving efficiency and enhancing decision-making (Friedman, 2015; Kamat et al., 2010; Wang et al., 2013; Wang and Dunston, 2013). The last application area refers to the provision of training and education. In a risk-free environment, efficiency and quality of education and training can be improved (Ervin, 2016; Kivrak et al., 2013; Wang et al., 2013).

In summary, the use of AR in combination with a HMD offers several intangible benefits which must be re-expressed in more measurable terms in the second step prior to being quantified. For example, the possibility of providing a better spatial sense of the building to customers by exploring the 3D model of the building and the flexible reflection of design and work sequence changes is expected to result in the intangible benefit *"improving customer relationship"* (Agarwal, 2016; Wang et al., 2013). Since this benefit is difficult to be quantified, it must be re-expressed in a more measurable term like *"increasing customer satisfaction"* which in turn can be measured with *"sales revenue"*. This proposed procedure is used by Murphy and Simon (2002) to re-express the intangible benefits similarly to those of the AR application scenario based on the estimations of senior managers. Although the risk of subjective justification can arise from the application of this method, it represents a practical way to assess the financial implications of the investment. However, IS investment projects are multi-stakeholder undertakings with different parties of stakeholders involved (Irani et al., 2006; Milis and Mercken, 2004). With this in mind, the evaluation of IS investment projects should take into consideration the objectives and expectations of all stakeholders. To do this, Anandarajan and Wen (1999) conduct panels of stakeholders to assess financial impacts of a computer-integrated manufacturing (CIM) investment. The combined use of management estimates and panels of stakeholders offers all stakeholders of a company the opportunity to provide their own perspective toward the investment and to mitigate subjective bias which may arise from the justification of the senior managers.

As can be seen from Table 2, most benefits of the application scenario are operational and tactical in nature, providing great potential for time and cost savings. Although not explicitly mentioned in the investigated scientific and practical publications, strategic benefits like *"improving growth and success"*, *"improving market share"* and *"improving corporate image"* are identified as indirect impacts. Additionally, we cluster the benefits in 3 categories following the classification of Irani and Love (2000). While operational benefits are generally tangible and quantitative, strategic benefits are usually intangible and non-quantitative in nature. Hence, the conversion of strategic benefits into monetary terms is considered as the most challenging task of the quantification process. Another difficulty within the quantification process lies in the third step of predicting the benefits in physical terms using the market approach, the cost approach or the income approach (Figure 2). In essence, the market approach aims to derive physical terms from benefits and costs of comparable projects in other organisations, while the cost approach attempts to quantify the benefits and costs based on the use of alternative technologies to achieve the same functionality. Based on management estimates, the income approach is focused on investigating how much additional income or cost reductions will result from the adoption of the new technology (Hares and Royle, 1994; Murphy and Simon, 2002). Following this given example, management estimates and panels of stakeholders can be conducted to predict the expected increase in customer satisfaction and the increase of sales revenue (Anandarajan and Wen, 1999; Murphy and Simon, 2002).

Due to the lack of real case studies as well as the fact that AR applications still remain at the last stages of development in practice, the third step is carried out by assuming amounts for the benefits in this paper. Similarly, assumptions are made concerning the costs of the investment.

5 Quantitative Analysis

5.1 Capital budgeting method VoFI

In previous and current literature, a wide range of methods have been proposed for the appraisal of IS investments (Renkema and Berghout, 1997). Despite the fact that traditional financial approaches like

Net Present Value (NPV), Internal Rate of Return (IRR) or Payback Period (PP) are often used as appraisal methods for IS investment projects (Ballantine and Stray, 1998; Irani et al., 2006; Milis and Mercken, 2004; Walter and Spitta, 2004), they mostly suffer from many drawbacks inherent in their underlying assumptions. In particular, these methods focus on the determination of the time value of money by adjusting all estimated cash flows back to the present (t = 0) using a uniform discount rate and based on the assumption of a perfect capital market which is far from reality (Götze et al., 2015).

To measure the financial consequences arising from long-term IS investments, the method of "Visualisation of Financial Implications" (VoFI) is considered as a more suitable capital budgeting method which can help to overcome the shortcomings of the traditional financial methods (vom Brocke and Lindner, 2004). Introduced by Heister (1962) and developed by Grob (1989), this method has been adopted by only a few researchers from the IS field (vom Brocke and Lindner, 2004; Götze et al., 2015; Jede and Teuteberg, 2016). Compared to traditional methods like NPV, this method offers researchers and practitioners the opportunity to transparently visualize the financial consequences of the investment proposals, based on realistic assumptions like individual conditions for fundings and loans as well as depreciation and taxes (Götze et al., 2015; Grob, 1989). In this paper, we intend to apply the method of VoFI due to its given transparency and adaptability. By means of VoFI, spreadsheets can be used to show all relevant parameters which impact the financial measures of the investment (vom Brocke and Lindner, 2004). Finally, the calculated measures can be used to assess the profitability of the project.

5.2 Quantitative analysis using VoFI

The VoFI method is based on a financial plan containing comprehensive information about the original and derivative cash flows, including various payback and interest conditions associated with the financial investments of the company. In order to handle the high amounts of data, Excel spreadsheets are considered as a suitable tool for assisting in the calculation process. Hence, the simulation of the CBA is performed by means of an Excel-based tool which has specifically been developed for this purpose[1]. The starting point of the simulation is the determination of the individual parameters (Table 3).

Economic life (t): 5				Tax rate:	40%	
Interest conditions				Amount	Interest	Duration
	Internal funds (IF)			20,000	3.00%	5
	Instalment loan (I)			25,000	5.00%	4
	Bullet loan (B)			25,000	5.00%	4
	Annuity loan (A)			20,000	5.00%	4
	Loan in current account (C)			30,000	10.00%	
	Financial investment (F)				2.00%	
	t = 0	t = 1	t = 2	t = 3	t = 4	t = 5
Net cash flow (CF)	-120,000	33,000	47,000	48,000	46,000	46,000
Total cash outflow	-120,000	-10,000	-10,000	-10,000	-10,000	-10,000
Total cash inflow	0	43,000	57,000	58,000	56,000	56,000

Table 3. Parameter settings.

This step includes the general parameter settings as well as the original cash flow resulting from the quantification process.

The original cashflow can be derived based on the assessment framework presented in section 4.2 and 4.3 which is integrated into the Excel-tool (sheet 2) for facilitating implementation. The data concerning the original cashflow as well as all other parameter settings are based on assumptions which are required for the simulation. Based on these settings, the derivative cash flow and the financial measures are calculated automatically by the spreadsheet. In each period, all in- and out-payments of the various loans as well as the financial investments and taxes are calculated and balanced in the VoFI table. As a result,

[1] The Excel tool is available at http://bit.ly/VoFI_ECIS

the net funding value of all in- and out-payments of each period has to be zero. In a further step, the net balance of all loans and funds is aggregated over time to determine the future value of the investment. Subsequently, financial measures like the net future value and the ROI can be estimated (Table 4).

Investment		Period	t = 0	t = 1	t = 2	t = 3	t = 4	t = 5
Series of net cash flows	**€**		**-120,000**	**33,000**	**47,000**	**48,000**	**46,000**	**46,000**
Internal funds	**€**							
- Withdrawal								
+ Deposit			20,000					
Instalment loan	**€**							
+ Credit intake			25,000					
- Redemption				-6,250	-6,250	-6,250	-6,250	
- Debitor interest		**5.0%**		-1,250	-938	-625	-313	0
Bullet loan	**€**							
+ Credit intake			25,000					
- Redemption							-25,000	
- Debitor interest		**5.0%**		-1,250	-1,250	-1,250	-1,250	
Annuity loan	**€**							
+ Credit intake			20,000					
- Redemption				-4,640	-4,872	-5,116	-5,372	
- Debitor interest		**5.0%**		-1,000	-768	-524	-269	
Loan in current account	**€**							
+ Credit intake			30,000					
- Redemption				-8,970	-18,002	-3,028	0	0
- Debitor interest		**10.0%**		-3,000	-2,103	-303	0	0
Financial investment	**€**							
- Reinvestment			0	0	0	-16,745	0	-37,329
+ Disinvestment			0	0	0	0	5,960	0
+ Creditor interest		**2.0%**	0	0	0	0	335	216
Taxes	**€**							
- Payment		**40.0%**		-1,000	-7,177	-8,519	-8,202	-8,886
+ Refund				0	0	0	0	0
Net funding	**€**		**0**	**0**	**0**	**0**	**0**	**0**
Balances	**€**							
on instalment loan			25,000	18,750	12,500	6,250	0	0
on bullet loan			25,000	25,000	25,000	25,000	0	0
on annuity loan			20,000	15,360	10,488	5,372	0	0
on loan in current account			30,000	21,030	3,028	0	0	0
on financial investment			0	0	0	16,745	10,785	48,114
Net balance	**€**		**-100,000**	**-80,140**	**-51,016**	**-19,877**	**10,785**	**48,114**
Financial measures								
Future value of investment								**48,114**
Future value of opportunity		**1.8%**						**21,866**
Net future value								**26,248**
Return on Investment								**19.2%**

Table 4. VoFI table and calculations based on the parameter settings.

In essence, an investment can be considered absolutely profitable if its net future value is positive or its ROI exceeds the opportunity interest rate (vom Brocke and Lindner, 2004; Götze, 2008; Grob, 1989). In this simulation run, the estimated net future value of 26,248 € and the ROI of 19.2% indicates that the calculated investment is profitable.

5.3 Risk assessment

The ex-ante evaluation of IS investments by means of a CBA requires the prediction of several input factors. Hence, the outcomes of the quantitative analysis are based on several assumptions and parameters. By conducting an additional sensitivity analysis, the effects of these different assumptions and parameters on the target measures can be explored (Sassone, 1988; Sassone and Schaffer, 1978; Savvides, 1994). The main aim of risk assessment is not only to improve the decision-making process by analysing how changes of input values may affect the results of the CBA, but also to understand the impacts of these factors on the overall measures (Jovanović, 1999).

A widespread form of sensitivity analysis refers to the calculation of an additional worst and best case scenario by varying the key input factors (e.g. cash inflows, cash outflows, interest rates) upwards and downwards and thus to estimate the overall effects on the target measures (Anandarajan and Wen, 1999). Table 5 shows an example of sensitivity analysis carried out on the total cash inflow as input factor. From the data it can be seen that a 10% decrease on the total cash inflow results in a decrease of 64.8% on the net future value and a decrease of 51.9% on the ROI. However, the net future value remains positive due to the large change of the output factor. As demonstrated in the example, the advantage of a sensitivity analysis lies in its simplicity and practicability. Unfortunately, it is not possible to incorporate the impact of uncertainty within this form of sensitivity analysis (Savvides, 1994). By means of this method, it is only possible to determine which of the input factors affects the target measures most (Anandarajan and Wen, 1999; Savvides, 1994). We apply sensitivity analysis on several input factors of our VoFI model. The results reveal that the total cash inflow is the most sensitive input factor, compared to other variables like the net cash outflow or the interest rates for different forms of loans.

	Input variable:	**Total cash inflow**	
Financial measures	**Worst case (-10.0%)**	**Base case (0.0%)**	**Best case (+10.0%)**
Net future value	9,242	26,248	43,101
Return on Investment	**9.2%**	**19.2%**	**26.6%**
Increase (+)/ Decrease (-) of net future value	-17,006	0	+16,852
Percentage change of net future value	**-64.8%**	**-**	**64.2%**
Increase (+)/ Decrease (-) of ROI	-10.0%	-	+7.4%
Percentage change of ROI	**-51.9%**	**-**	**38.4%**

Table 5. Sensitivity analysis of total cash inflow as input factor.

Risk considerations in cost-benefit analyses can also be made by conducting probabilistic risk analysis, a more complex form of sensitivity analysis (Ho and Pike, 1992; Sassone and Schaffer, 1978; Savvides, 1994). Based on the Monte-Carlo simulation technique, a plenty number of simulation runs of the mathematical model can be computed in an appropriate simulation tool by using probability distributions of the key input factors. According to Savvides (1994), the determination of objective risk variables for ex-ante investment appraisals is not possible due to the non-availability of certain data. Hence, subjective judgements based on management and stakeholder estimates are sufficient to provide probabilities for the risk analysis. As such, Savvides (1994, p. 8) states that *"probability distribution profiles are used to express quantitatively the beliefs and expectations of experts regarding the outcome of a particular future event"*. Possible outcomes of a probabilistic risk analysis are not only a probability distribution of all possible target measures, but also a complete risk/return profile of the investment project.

The incorporation of Monte-Carlo simulations into the VoFI-based decision model is carried out in this paper by using the Excel Add-in Crystal Ball and following the approach for risk analysis provided by Grob and Hermans (2009) and Savvides (1994) shown in Figure 3. The first stage of the preparation phase has already been done in the previous section by developing the Excel-based VoFI spreadsheet. Also, we have identified the total cash inflow as one sensitive and uncertain input factor to be further investigated. In a further step, we make another simplifying assumption to determine a normal probability distribution for the total cash inflow in each period with a standard deviation of 10% from the mean value by means of the function *"Define Assumption"* in Crystal Ball. The target measures of the VoFI are then selected to be simulated during the execution phase. In practice, step 2 and 3 of the preparation stage have to be conducted by using subjective judgement of managers and other stakeholders.

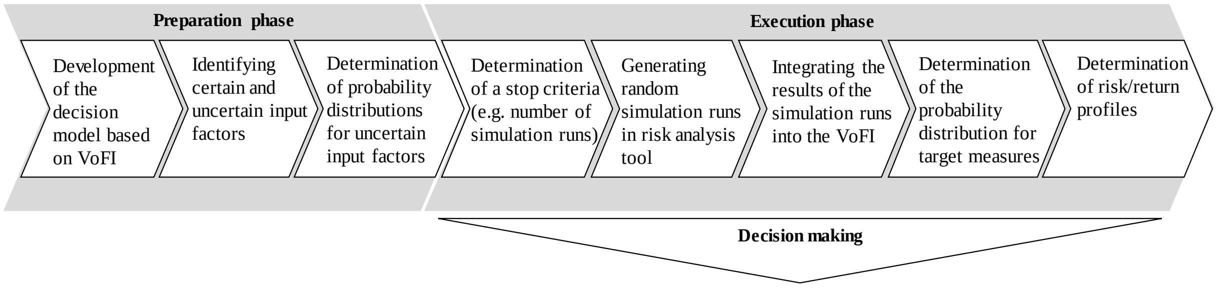

Figure 3. Risk analysis procedure based on Grob and Hermans (2009) and Savvides (1994).

During the execution phase, we conduct 1.000 simulation runs to generate random scenarios in the Excel Add-in Crystal Ball. As the results of these simulations are directly integrated into the VoFI model, the probability distribution for the target measures are calculated simultaneously. As a final step, the risk/return profile of the investment is determined to provide the decision maker the opportunity to assess the probability of a certain target measure. In our example illustrated in Figure 4, the probability distribution of the investigated target measure based on the conducted simulation runs reveals that a net future value of at least 13,390 € can be realised with a certainty level of 90%.

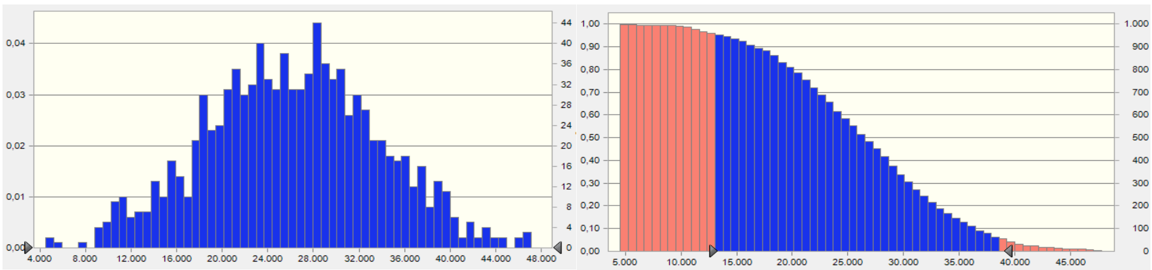

Figure 4. Probability distribution and Reverse Cumulative Chart of the net future value.

The probability risk analysis finally ends up with the decision-making process. Although the results of a risk analysis can serve as a helpful aid for handling decision-making problems under uncertainty, the final decision remains a subjective task. In general, managers are likely to invest in projects with the probability distribution of target measures that best suits their own personal preferences towards risk. As a consequence, managers who are willing to take risks tend to invest in projects with high returns but a high risk-level, whereas risk averse managers will probably invest in projects with relatively low but safe returns (Savvides, 1994).

5.4 Evaluation

The evaluation of our artefacts consists of semi-structured expert interviews which are conducted face to face. Overall, 6 experts are asked to evaluate the cost and benefit framework as well as the Excel tool based on a list of evaluation criteria adapted from Sonnenberg and Brocke (2011). Each interview has a duration of about 30 minutes. All experts are industry practitioners with different professional backgrounds. All of them have many years of professional experience in accounting, investment appraisals or in developing tools and methods for the use in construction. During the interviews, we ask the experts to use the Excel-tool with no further support and to evaluate the artefact based on their experience with it. For this purpose, we make use of the "Thinking aloud"-method to capture all impressions (Boren and Ramey, 2000; Holzinger, 2005).

Overall, the artefacts are considered as a useful instrument for the appraisal of IS investment proposals. Also, the completeness and internal consistency of the cost-benefit framework has been confirmed. However, several practitioners have problems in estimating the cash inflows associated with the benefits of the application scenario. In essence, they argue that intangible benefits are not measurable due to their vague nature. For example, one expert states: *"It might be that the costs are easy to predict. But as far as the benefits are concerned, I have no idea how to estimate them. […] How do you know that the economic effects of the investment are caused by benefit number one, two or three, or even by none of them?"*. Another expert even believes that the measurement of intangible benefits could be abused by decision makers to promote their own interests by overestimating the benefits and underestimating the costs, making this following comment: "*If I want my investment to be realised, I simply have to put a larger amount to the intangible benefits and a smaller one to the costs."* As far as the VoFI spreadsheets are concerned, several participants have difficulties in dealing with the complexity of the VoFI method and the financial terminologies used in this context. To address this deficiency, we have modified the VoFI spreadsheets (choice of language, clearer terminology, etc.) with the purpose to enhance the understandability and the ease of use for decision makers. As a next step, the decision support tool will be tested in a real corporate context for a continuous improvement.

6 Discussion

Retrospectively, the evaluation of our artefacts based on the expert interviews indicates that the constructed assessment framework is considered suitable for serving as an instrument for the evaluation of the specific application scenario at the proposal stage. Furthermore, the results of our research are expected to be of value for research and practice for several reasons. First, our paper addresses the timely need for IS investment appraisals of innovative technologies in the context of Industry 4.0, such like the combined use of AR and wearable devices like Smart Glasses or HMD. Second, we rely on the well-established knowledge base in the area of IS investment evaluation to provide a more efficient solution for an old organisational problem.

However, we do not consider our research complete. Our design-science oriented approach primarily aims to provide a practical way to assess costs and benefits of the AR application scenario by consequently incorporating all intangible costs and benefits. As every quantitative approach, our work shows several limitations which have to be kept in mind. Furthermore, there exist many unanswered questions concerning the incorporation of costs and benefits in financial appraisals that we cannot address in one research undertaking. With this in mind, the limitations and implications for future research can be summarised as follows to provide guidance to future researchers:

- *Intangible benefits:* The process of assigning values to the intangible benefits remains one of the most challenging tasks within a CBA. The key questions that future research needs to answer is how to systematically measure intangible benefits in considering the complex cause effect relationships between these benefits and their financial impacts.
- *Boundaries of the system:* As addressed by other researchers, it is difficult to determine the boundaries of a single IS. For example, the question arises how to separate costs and benefits of the AR investment from others, e.g. whether costs in the BIM environment (for BIM contents) should be counted as costs of the AR application scenario or as costs concerning the BIM system.
- *Data collection:* Our approach consists of a simulation model which is based on several assumptions and parameters. As such, the lack of "real-life" empirical data is one major problem to be solved in further studies. Potential cost savings and benefits should be proven and validated by means of field experiments and case studies. Also, a comprehensive market analysis should be carried out to investigate the cost structure of the proposed application scenario.
- *Hidden costs and benefits and the problem of overlaps* are major issues that deserve more attention in future CBA. In our example, it is difficult to ensure that certain benefits like *"improving quality"* and *"improving efficiency"* are not double-counted during the quantification process.

- *Arbitrary decision-making:* As has been outlined by many researchers, the social and subjective nature of IS investment evaluation is contradictory to the formal-rational nature of traditional appraisal methods like a CBA (Serafeimidis and Smithson, 2003; Walter and Spitta, 2004). Indeed, arbitrary behavior is considered as one problem to be faced within the decision-making process. Managers tend to search and select a solution that satisfies their own preferences rather than searching for an optimal solution in a real life situation (Simon, 1955). This behaviour of bounded rationality possibly occurs as the act of underweighting or overweighting of probabilities to justify decision-making tendencies of the manager. To address these deficiencies, the design of decision support systems must further be focused more intensively in future research. To ensure that the outcomes of the investment evaluation not only depends on management judgements and serves management objectives, it could be useful to involve all groups of stakeholders (users, employees, implementers and others) into the evaluation process (Irani et al., 2006).
- The *adoption of innovations* such like AR is a complex long-term process that might be influenced by a number of different factors. The academic discussion in this research area has yet resulted in various theoretical frameworks for the adoption of innovations, e.g. the Technology-organisation-environment framework (Depietro et al., 1990) or the Diffusion of innovations theory (Rogers, 2010) to describe the main antecedents, constraints and opportunities to the adoption of innovations in the organisational context. Other related research streams are focused on investigating and understanding the influencing factors of IS business value, e.g. the IS success model of Delone and McLean (2003) or the Technology acceptance model (Davis, 1989). In considering the multitude and complexity of the influencing factors of IS success, the outcomes of a CBA should be considered as one input to the decision process. The final investment decision should take into consideration other contextual factors as well.

Notwithstanding the preceding discussion, we suggest that future research should continue to address the issues mentioned above to overcome the challenges associated with investment appraisals. Due to the increasing digitisation of the business and manufacturing environment, the evaluation of IS investments at the proposal stage remains one of the most important tasks in the corporate context.

7 Conclusion

In today's dynamic corporate environment, the evaluation of IS investments is considered as an essential influencing factor for the pace of business automation. The use of AR in combination with HMD and Smart Glasses for construction purposes has been described by researchers as an application scenario with far-reaching benefits and positive impacts on the company's performance. However, none of them has proposed tools or methods to estimate these benefits and costs associated with the adoption of this new technology.

Previous and current literature in the area of IS investment evaluation has suggested a variety of principles, methods and techniques to quantify costs and benefits for IS investments. Drawing on this body of knowledge, the main aim of this paper is to derive costs and benefits for the application scenario and to demonstrate how a traditional CBA can be applied more effectively to assist in the decision-making process. In doing so, we do not only place emphasis on the provision of financial implications for the AR-based application scenario itself, but rather on the understanding of how to develop such a CBA for other IS investments. The method of VoFI has been selected as appraisal method, as it offers transparency and adaptability by considering a wide range of different input factors that are closer to reality than in traditional methods. By using an appropriately designed decision support tool in combination with a risk analysis, the financial consequences of the investment can be evaluated in an adequate manner.

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