Situated visualization in the decision process through augmented reality

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***Abstract* — The decision-making process and the development of decision support systems (DSS) have been enhanced by a variety of methods originated from information science, cognitive psychology and artificial intelligence over the past years. Situated visualization (SV) is a method to present data representations in context. Its main characteristic is to display data representations near the data referent. As augmented reality (AR) is becoming more mature, affordable and widespread, using it as a tool for SV becomes feasible in several situations. In addition, it may provide a positive contribution to more effective and efficient decision-making, as the users have contextual, relevant and appropriate information to endorse their choices. As new challenges and opportunities arise, it is important to understand the relevance of intertwining these fields. Based on a literature analysis, this paper addresses and discusses current areas of application, benefits, challenges and opportunities of using SV through AR to visualize data in context and to support a decision-making process and its importance in future DSS.**

Keywords — Situated visualization, augmented reality, decision-making and decision support systems.

I. INTRODUCTION

Over the past years, technology has been enhancing the way we perceive and act in the world around us. An example of this is the use of Decision Support Systems (DSS) to aid in the process of decision-making in numerous scenarios; these systems have been an active subject of scientific research and are at the crossroad among a variety of areas as information science, cognitive psychology and artificial intelligence. Another such area is what is called situated visualization (SV), the presentation of data in their spatial and semantic context, to aid in complex decision-making processes. Similarly, the evolution of augmented reality (AR) made possible solutions that were only theoretical subjects of study. As AR is becoming more affordable, mature and widespread, using it as a tool for SV in DSS is becoming viable in several situations. The growing interest in these fields and their combined potential, highlights the importance to address and understand the current contributions provided by SV using AR in the decision-making process.

This paper addresses this topic based on a literature analysis and presents the main concepts and usages as well as the possible benefits and challenges. It also identifies research opportunities which combine these fields. It is organized as follows. Section 2 and 3 introduce the concepts of augmented reality, situated visualization, decision-making and decision support systems based on illustrative examples. Then, section 4 discusses the potential and benefits of their convergence and identifies current areas of application and research opportunities. Finally, section 5 presents concluding remarks.

II. AUGMENTED REALITY AND SITUATED VISUALIZATION

A. Augmented reality

The concept of AR can be described as a "novel human machine interaction tool that overlays computer-generated information in the real-world environment. The information display and image overlay are context-sensitive, which means that they depend on the observed objects" [1]. This definition is not limited to a specific sense. AR has the potential to be applied to all senses (vision, touch, hearing, smell, taste) [2], displaying information not directly available or detectable by the human senses [3][4].

AR may be viewed as an intermediate step between virtual reality (VR) presenting a virtual world and the unmodified real world in the "mixed reality continuum", proposed by Milgram and Kishino [5]. Both VR and AR have the goal of immersing the user, although these two different paradigms use different approaches to accomplish this goal. While VR offers a digital recreation of a real-life environment, AR uses computer-generated technology to blend virtual reality and real life, displaying virtual elements as an overlay to the real world, making it more meaningful through the ability to interact with existing virtual elements. Interaction with these elements may provide a different perception of the real world and thus a richer experience [5].

While not bound to any displaying technology, as it can be based on desktop, projectors, head-mounted or mobile devices [6], current AR solutions have been implemented mostly as applications for mobile devices, using the device camera to detect markers and deploy an enhanced version of the environment by blending digital components into the real world. However, when the virtual content needs to be overlaid directly on the surface of a real object, using a projector has more benefits as it provides the natural coincidence of vergence and accommodation of the human visual system (an issue with the other types of solutions). This does not require devices to be worn or held, which is particularly relevant for task performance and collaborative settings.

Concerning display technologies, AR approaches have been classified into two types: visual augmented reality (VAR), when the virtual content is overlaid into the user's visual field and spatial augmented reality (SAR), when the virtual content is overlaid on the physical space [7].

AR, unlike VR, does not aim to fully remove the physical environment, but to present virtual stimuli, while keeping the sense of presence from the individual experiencing it, trying to improve reality, instead of replacing it [8]. Depending on the context, AR may take advantage of two different references: visual clues/labels to provide additional information regarding real world elements (see Fig. 1) to know when and where to present the virtual content, which is currently the most used; location-based placing content according to the real-world geographic location and an estimation of the user's viewpoint (e.g. using GPS and other sensors).

Fig. 1. Examples of visualization in context using augmented reality (AR) to provide visual cues to assist in the assembly of eletronic circuits [9].

B. Situated visualization

The concepts of mobile and outdoor solutions adapt perfectly to the paradigm of AR, not being confined to a single place, allowing interaction in the field using different types of tracking (e.g. markers, sensors, GPS) and interface (e.g. handheld devices, headgear, etc.) [10]. This serves as basis to the concept of SV, referring to a visualization related to its environment, gaining meaning "through the combination of the visualization and the relationship between the visualization and the environment" [11][12][13].

It should be noted, however, that using AR technology to display visualizations does not imply that the visualizations are situated, as it is the case when they are not connected to a real-world entity (and might as well be presented by a VR system) [14]. Examples of this visualization type can be found in [15] and [16]. On the other hand, the definition of situated visualization is agnostic to the type of data being visualized, abstract or physically-based. Both can be situated with the advantage of being displayed and explored directly in the spatial reference frame of the real world [14]. Examples of abstract data are visualized in [17] and [18], and physically-based data in [19], [13] and [20]. Some examples of these works are presented on Fig. 2.

Fig. 2. Examples of Situated Visualizations (left) and Non-Situated Visualizations (right). (A) [25] and (B) [13] present information about a product and a street, situating them accordingly. (C) [16] and (D) [1] present non-situated information in an AR scenario.

Thus, the main defining characteristic of SV is this association of the data represented to where they are displayed in relation with the data referent; spatial "situatedness" may be on a continuum as, for instance, a visualization projected on a physical object is spatially "more situated" than a visualization viewed on a smartphone near the referent, which in turn is spatially more situated than the same visualization shown on a desktop [7]. Moreover, the concept of situatedness can be extended beyond physical location of the representations and involve other aspects as perceptual and temporal.

Fig. 3 shows the conceptual model of situated visualization, proposed by Thomas et al., in [7], based on the models of two related concepts: embedded visualization, by Willett et al. [21], and beyond-desktop visualization, by Jansen and Dragicevic [22]. This model shows the interaction with the visualization pipeline (pertaining to all interactive visualizations), as well as interaction with the physical referent and the physical representation (e.g. moving them), specific to Situated Visualization. This allows physical action to follow analytical reasoning and decision-making, more promptly than when visualizations are not situated; also, if the system is real-time and the physical referent is the data source, analysis and action can be interweaved, including altering the data [7].

Willett et al., in [21], differentiate embedded from situated representations, as the latter show data near data referents, while embedded representations show the data so that they spatially coincide with data referents (i.e. physical spaces, objects and entities to which the data refers) [7]. The concept of embedded visualization has a more limited scope and introduces more challenges; though, both are closely related to the recently defined research field of immersive analytics [23][24], as well as situated analytics (SA) [25][26], which implies the "use of data representations organized in relation to relevant objects, places and persons for the purpose of understanding, sense-making and decision-making." [7].

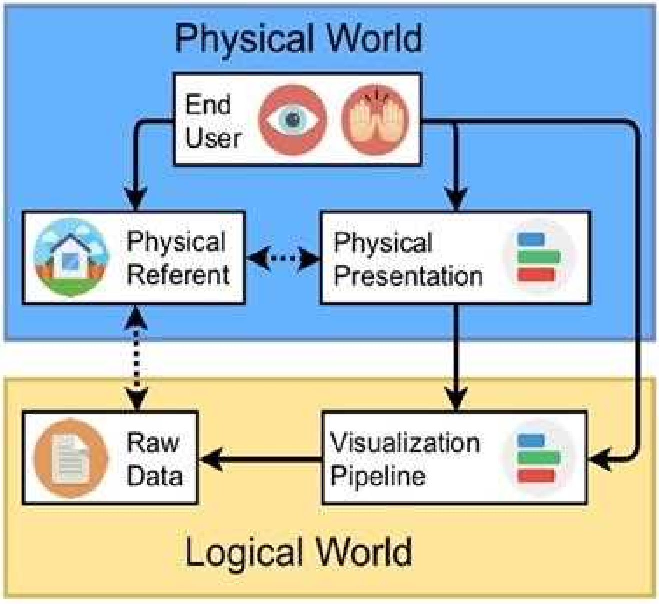

Fig. 3. Conceptual model of situated visualization (SV) including interaction between the Physical World and the Logical World (adapted from [7]).

Due to the increasing number of AR frameworks and the decrease in hardware costs, the number of AR applications has been growing in different fields [27] such as education (e.g. a real time cosmic scanner), tourism (e.g. maps that use AR tips to show information regarding places of interest), marketing (e.g. Rayban® virtual mirror to try on glasses), maintenance (supporting equipment or appliances maintenance procedures), among others. There are works in these topics that can be viewed as situated visualizations [26].

It should be noted that SV is technology agnostic, not assuming any specific technology, not even implying the use of AR, yet as Thomas et al., in [7], point out "new and emerging technologies make it possible to create elaborate forms of situated visualizations".

SV has several potential benefits when compared to traditional AR-based visualizations; yet, it implies challenges that impact their applicability and usefulness. Willet et al., in [21], discuss these trade-offs and point-out research challenges. In addition to the traditional challenges inherent to visualize data, SV presents additional difficulties due to the fact that the visual representations are presented through AR, namely the dynamic and distracting nature of the real world. These specific challenges are, according to [14], visual and temporal coherence, visual interference, egocentric viewpoint and registration with the real world. Also, according to Thomas et al., in [7], analytics moving into the "real world" raises challenges at technical, methodological and conceptual level. SA fosters a more "casual" approach to analytics than the traditional data analysis using a desktop and this will involve rethinking how to design, implement and evaluate situated tools, entailing new methods, guidelines and frameworks. The creation of immersive visualizations in the SV applications is still a challenging task. Sicat et al., in [28], present a new framework that tries to expedite it, offering developers an efficient way to specify visualization designs by using a concise declarative visualization grammar.

III. Decision-Making and Decision Support Systems

The process of decision-making has been a major focus of several science fields, developing various methods for making rational choices. "Good decision-making" means users are informed and have relevant and appropriate information on which to base their choices, among multiple alternatives [29].

Methods enhanced by a variety of approaches have been developed using computer programs with the goal of helping in the complex process of decision-making. Such environments are often given the common name of decision support systems (DSS) [30]. "The DSS area, as a subject of research and practice, continues to grow along ever-widening horizons – often blending with other major IS expansions such as (…) pervasive computing." [31]. It is noteworthy that more than a decade ago, the DSS community was already aware of the importance of supporting decision-makers "anytime anywhere", which SA (in general) and SV (more specifically) may provide.

DSS is a broad area of research and practice [32] and different people have perceived the field from various vantage points and report different accounts of what was important [33][34]. While there have been several definitions of a DSS, a definition that seems generally accepted is a computer-based system that in some way assists in decision-making [35]. In contrast, a decision can be viewed as "a non-random activity culminating in the selection of one from among multiple alternative courses of action" [36].

Some common and accepted characteristics of a DSS found in the literature [37] are the following: should be designed specifically to facilitate the decision process, support rather than automate decision-making; and be able to respond quickly to the changing needs. It is also possible to list several other characteristics, which allow a broader perspective on the DSS concept [38][39][40], such as: should be adaptable, flexible and easy to use; facilitate specific decision-making activities and/or decision processes; and support decision-makers at any level in an organization; should also be improved over time to deal with changing conditions; be used routinely or used as needed for ad hoc decision support tasks; execute sensitivity analysis and improve the accuracy, timeliness, quality as well as the overall effectiveness of independent and/or sequential decisions.

It is possible to classify DSS concerning the mode of assistance provided [41][42][43], and the following five categories may be identified: model-driven (emphasizing access to and manipulation of statistical, optimization, or simulation models), communication-driven (supporting more than one person working on a shared task); data-driven (emphasizing the access to and manipulation of data); document-driven (managing, unstructured information in a variety of electronic formats); and knowledge-driven (providing specialized problem-solving expertise stored as facts, rules and procedures).

Whereas visualization may leverage the capacity of virtually all types of DSS and decision tasks to support the decision process, SV may extend this applicability beyond the desktop through AR, paving the way to the pervasive computing paradigm, which envisions providing support to decision-makers "anytime, anywhere" [44]. The next section elaborates further on how it may be attained.

IV. SITUATED VISUALIZATION IN DECISION-MAKING

It is long recognized that visualization augments human memory in different ways as humans can process visual cues in parallel, visualization may enhance both working memory and long-term memory. It can augment working memory while extending memory and visual cognition [45], serving as an external memory, saving space in working memory, as well as facilitating internal computation and the comprehension of domain knowledge, fundamental in making future decisions. Moreover, visualization helps users find and understand patterns in large amounts of data and may be applied to assist the information acquisition to support a decision-making process. It can be useful not only to help reach a decision, but also to explain the process and the decision [46]. An illustration example can be seen on Fig. 4. In this example, a user makes a simple decision of selecting a fruit to buy. The visualizations can show nutritional values, prices, harvest details and known allergens. In a stand with various fruits, situated visualization can ease this decision.

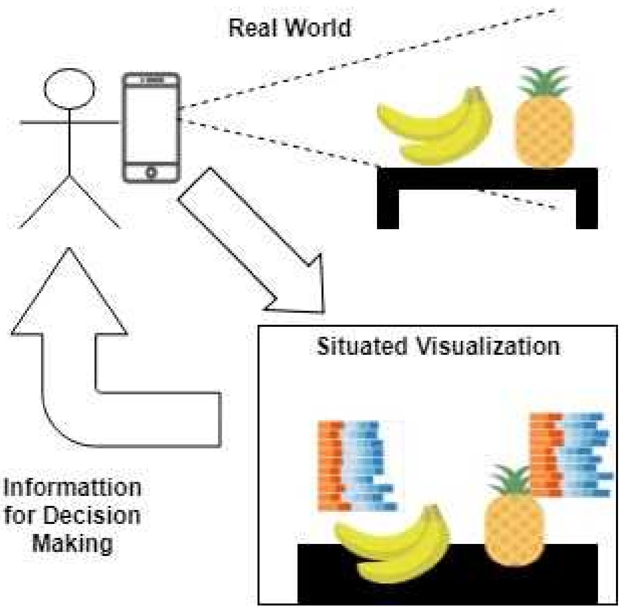

Fig. 4. Illustrattive example for the simple decision of selection based on a situated visualization of data corresponding to each alternative item.

Four approaches may be used to assess alternatives in a decision process: analytical, subjective, judgmental and bargaining. The last is used in group decisions, while the remaining approaches may be used in individual decisions and involve obtaining information from various sources and may be supported by visualization. The analytical approach involves using mathematical models; in subjective approach decision-makers draw subjective conclusions based on data and opinions they collect, and when using the judgmental approach, they are based on their intuitions rooted in their domain knowledge, previous experience and awareness of the situation. According to Zhu and Chen, in [46], all these approaches may be supported by visualization, more or less directly, as it helps users grasp patterns from large amounts of data increasing knowledge and awareness. According to these authors, in 2008 the adoption of visualization in decision support was still at an early stage and very few successful cases had been published. Moreover, while previous works had explored how visualization affects decision-making and tried to find the interaction between visualization and decision-making, few studies had established the relationship between the type of decision-making tasks and specific visualization technologies. These authors also addressed the impact of visualization on decision-making at the individual level and the role that information visualization might play while supporting different decision-tasks and recognize that there is no universal visualization that work for all decision-making tasks. Thus, a specific visualization must take the characteristics of decision tasks and decision-makers in consideration if it should facilitate a decision process. This is in-line with the now widely accepted user-centred approach to the design of effective visualization systems [47].

As SV extends the applicability of visualization beyond the desktop, it enhances sense-making by making the information presentation more understandable through the association with the appropriate physical objects. Also, SV can provide a more natural interaction, since the user can touch and manipulate physical objects, easing information analysis based on contextual information and helping decision-making [7]. Even though it is easily understood that SV may provide clear benefits to a decision process happening beyond a desktop, its usage along with a DSS seems still scarce, perchance due to the emerging nature of SV. However, we argue that it will become more common in the near future as a consequence of advances in theory and its supporting technology. Next, we present some examples of the usage of AR to assist in decision process, which we argue may be viewed as SV (even though they were not qualified as such by their authors) and may provide inspiration to other application areas.

A. *Examples of current usage*

Only a reduced number of applications using AR with DSS can be found in literature. However, some interesting and exploratory examples using AR to help decisions can be presented. One early example is the SARDE system (Spatial Augmented Reality Design Environment) proposed by Chen and Chang [48] to support interior design students in their design decisions, which gave them more confidence in presenting their projects. Another example is the use of AR for training and decision-making in maintenance and assistance [49]. In this case AR covers the necessity of having an interactive, intuitive and time-saving learning tool, which can be used as an assistance for maintenance processes, facilitating the access to component specifications and the steps to follow to perform specific tasks, aiding technicians and operators on decision-making (supported by the associated DSS which acts based on data provided accordingly to each specific task); this leads to a faster comprehension of the system, as well as a more efficient intervention. Another relevant example is a system that uses AR and DSS for housing health and safety [50]. The system detects CO2, NO2, as well as other indicators and the DSS provides personalized suggestions for upgrading the living conditions, while AR offers real-time information about specific locations. The authors claim that through these improvements it is possible to generate conditions for a better quality of life, lower illness rates and increase the residents' work productivity. Finally, a recent example is the work by Milovanovic et al. [51], who propose a system, using VR and SAR to support collaborative design and decision-making in architectural education. All these examples may be viewed as being able to provide situated visualizations to their users when they view representations of architectural structures on physical 2D plans, data concerning pollutants on a property location, or component specifications on a circuit board, assisting the user's decisions, even when there is not a conventional DSS. We argue that these examples are harbingers of a type of system combining situated visualization based on augmented reality and decision support, which may have many application areas and become more pervasive and affordable as technologies and theory evolve (as expected to happen in the near future), probably presenting hard challenges, yet offering potential benefits and research opportunities.

B. Benefits, challenges and opportunities

The main potential benefits of DSS are, according to the literature [30][38][49][50][51][52]: time savings; higher efficiency and effectiveness; cost reduction, greater decision-maker satisfaction, higher productivity; better interpersonal communication, all potentially providing competitive advantages. Also using a DSS encourages the decision-maker to explore and discover by revealing new approaches to think about the problem and generating new evidence to support a decision.

Also, the literature analysed suggests SV using AR to support DSS may have the following benefits: allow the creation of memorable sensory experiences, capable of captivating attention and connection; allow exploring data rapidly and intuitively, contributing to quicker learning and high work productivity, promoting a faster understanding of the available options and facilitate earlier detection of possible flaws, and thus increase decision-maker satisfaction. Therefore, it seems reasonable to assume that the integration of SV systems will allow further enhancement of the characteristics of DSS.

As the examples presented in the previous section suggest, DSS enhanced by SV could act as tools to help in architectural design, construction, as well as industrial maintenance, training and safety management, easing design collaboration and discussion by augmenting specific data from the DSS with interactive interfaces, allowing to explore data rapidly and intuitively. It is possible to envisage other application areas (as natural sciences or marketing and shopping) that might benefit from the engaging and memorable sensory interactive experiences offered by SV (through AR) that cannot be recreated by traditional methods to support decisions. These experiences may, if properly designed, considering the users, their tasks and context, facilitate understanding of phenomena and promote better decisions.

Research and development regarding DSS will continue to explore new developments and we expect in the near future an increased adoption of SV solutions in DSS. Likewise, DSS will benefit from significant progress in fields such as simulation, optimization, artificial intelligence, machine learning, human-computer interaction, data mining, software engineering, as well as from research in behavioural topics as organizational decision-making, planning and organizational behaviour [43]. Advances in these fields are expected to contribute in increasing the effectiveness of individual and group decisions.

V. CONCLUDING REMARKS

Decision-making has always been immanent to human nature. However, the use of decision support systems to support the process of decision-making only gained momentum over the past years, through the use of computer programs and being subject of scientific research. Similarly, situated visualization systems able to present data in context and thus aid in complex decision-making have evolved and found applications in the last decade. On the other hand, using augmented reality as a tool for SV in DSS has become feasible, since AR is now more mature, and affordable.

This work explored and discussed the benefits, challenges and opportunities of using AR for SV in the process of decision-making and DSS, based on a literature analysis. The growing interest in these fields and their combined usage suggest that the integration of SV through AR will allow enhancing even more the characteristics of DSS (e.g. allowing exploring data rapidly and intuitively, earlier detection of possible flaws, high work productivity, among others), which means users can be more informed, have relevant and appropriate information to endorse their choices, thus allowing more effective and efficient decision-making. Even though a reduced number of works could be found, some interesting exploratory examples were identified, suggesting these benefits could improve tools to assist in architectural design, construction, as well as industrial maintenance, training and safety management.

Likewise, new challenges and opportunities for researchers arise, that had been impossible to explore until now. Hence, research and development regarding the process of Decision-making and DSS should continue to explore new theory and technology developments associated with AR and SV, taking advantage of several features, mainly the benefits of natural and interactive interfaces and environments, which may contribute to faster comprehension of the available options, easing design collaboration and discussion leading to more efficiency and effectiveness support of individual and group decisions.

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REFERENCES

[1] A. Nee, S. K. Ong, G. Chryssolouris, and D. Mourtzis, "Augmented reality applications in design and manufacturing", CIRP Annals-manufacturing technology, vol. 61, no. 2, pp. 657–679, 2012.

[2] R. Azuma, Y. Baillot, R. Behringer, S. Feiner, S. Julier, and B. Macintyre, "Recent Advances in Augmented Reality", *Comput. Graph. Appl.*, vol. 21, no. 6, pp. 34–47, 2001.

[3] R. Azuma, "A Survey of Augmented Reality," in *Presence: Teleop. and Virtual Environments*, vol. 6, no. 4, pp. 355–385, 1997.

[4] W. Robinett, "Synthetic Experience: A Proposed Taxonomy," *Presence: Teleoper. Virt.. Environ.*, vol. 1, no. 2, pp. 229–247, 1992.

[5] P. Milgram and F. Kishino, "A taxonomy of mixed reality visual displays," *IEICE Tr. Inf. Syst.*, vol. 77, no. 12, pp. 1321–1329, 1994.

[6] R. Azuma, "Making Augmented Reality a Reality," Applied Industrial Optics: Spectroscopy, Imaging and Metrology, pp. JTu1F-1, Optical Society of America, June 2017.

[7] B. H. Thomas, G. F. Welch, P. Dragicevic, N. Elmqvist, P. Irani, Y. Jansen, D. Schmalstieg, A. Tabard, N. A. M. ElSayed, R. T. Smith, and W. Willett, "Situated analytics," in Immersive Analytics, vol. 11190 LNCS, K. Marriot. et al., eds. Springer, , pp. 185–220, .2018.

[8] D. R. Berryman, "Augmented reality: a review," Medical reference services quarterly, vol. 31, no. 2, pp. 212–218, 2012.

[9] B. Marques, R. Esteves, J. Alves, C. Ferreira, P. Dias, and B. S. Santos, "Investigating different Augmented Reality Approaches in Circuit Assembly: a User Study," in Eurographics 2019, 2019, pp. 45–48.

[10] C. Arth, R. Grasset, L. Gruber, T. Langlotz, A. Mulloni, and D. Wagner, "The History of Mobile Augmented Reality-Developments in Mobile AR over the last almost 50 years," Un.iv of Graaz, 2015.

[11] S. White, P. Morozov, O. Oda, and S. Feiner, "Progress towards Site Visits by Situated Visualization," in *Proceedings of ACM CHI 2008 Workshop: Urban Mixed Reality*, 2008.

[12] White, S., Interaction and Presentation Techniques for Situated Visualization, PhD Thesis, Columbia Un., New York, NY 2009.

[13] S. White and S. K. Feiner, "SiteLens : Situated Visualization Techniques for Urban Site Visits," *Proc. 27th Int. Conf. Hum. Factors Comput. Syst.*, pp. 1117–1120, 2009.

[14] M. Tatzgern, "Situated Visualization in Augmented Reality," PhD Thesis, University of Graaz, 2015.

[15] A. Fuhrmann, H. L¨offelmann, H., and D. Schmalstieg, "Collaborative augmented reality: exploring dynamical systems," in *Proc. IEEE Visualization '97*, pp. 459–462, 1997.

[16] B. S. Meiguins, R. M. C. Do Carmo, A. S. Gonçalves, P. I. A. Godinho, and M. B. De Garcia, "Using augmented reality for multidimensional data visualization," Proc. Int. Conf. Inf. Vis., pp. 529–534, 2006.

[17] R. Grasset, T. Langlotz, D. Kalkofen, M. Tatzgern, and D. Schmalstieg, "Image-driven view management for augmented reality browsers," ISMAR 2012 - 11th IEEE Int. Symp. Mix. Augment. Real. 2012, Sci. Technol. Pap., pp. 177–186, 2012.

[18] R. Bach, H. Sicat, H. Pfister, and A. Quigley, "Drawing into the AR-Canvas: Designing Embedded Visualizations for Augmented Reality," Work. Immersive Anal. IEEE Vis, 2017.

[19] M. Eissele, M. Kreiser, and T. Ertl, "Context-controlled flow visualization in augmented reality," in Proceedings of Graphics Interface, 2008, pp. 89–96, 2008.

[20] G. Schall, E. Mendez, E. Kruijff, E. Veas, S. Junghanns, B. Reitinger, and D. Schmalstieg, "Handheld Augmented Reality for underground infrastructure visualization," *Pers. Ubiquit. Comp.*, vol. 13, no. 4, pp. 281–291, 2009.

[21] W. Willett, Y. Jansen, and P. Dragicevic, "Embedded Data Representations," IEEE Trans. Vis. Comp. Graph., vol. 23, no. 1, pp. 461–470, 2017.

[22] Y. Jansen, P. Dragicevic, A. Interaction, V. Beyond, T. Desktop, Y. Jansen, and P. Dragicevic, "An Interaction Model for Visualizations Beyond The Desktop," IEEE Trans. Vis. Comp. Graph., vol. 19, no. 12, pp. 2396–2405, 2013.

[23] T. Dwyer, N. H. Riche, K. Klein, W. Stuerzlinger, B. Thomas, "Immersive Analytics," Report from Dagstuhl Seminar 16231, 2016.

[24] T. Dwyer, N. H. Riche, K. Klein, W. Stuerzlinger, B. Thomas, "Immersive Analytics: An Introduction. In: K. Marriott et al. (eds) Immersive Analytics. LNCS, vol 11190, 2018.

[25] N. ElSayed, B. H. Thomas, R. T. Smith, K. Marriott, and J. Piantadosi, "Using augmented reality to support situated analytics," 2015 IEEE Virtual Real. Conf. VR 2015 - Proc., pp. 175–176, 2015.

[26] N. ElSayed, B. H. Thomas, K. Marriott, J. Piantadosi, and R. T. Smith, "Situated Analytics: Demonstrating immersive analytical tools with Augmented Reality," *J. Vis. Lang. Comput.*, vol. 36, pp. 13–23, 2016.

[27] M. Mekni and A. Lemieux, "Augmented Reality : Applications, Challenges and Future Trends," *Appl. Comput. Sci. anywhere,* pp. 205–214, 2014.

[28] R. Sicat, J. Li, J. Young Choi, M. Cordeill, W.-K. Jeong, B. Bach, and H. Pfister, "DXR : A Toolkit for Building Immersive Data Visualizations," *IEEE Trans. Vis. Comp. Graph.*, vol. 25, no. 1, pp. 715–725, 2019.

[29] V. Sauter and A. Wiley, Decision Support Systems for Business Intelligence, 2nd Edition. 2010.

[30] Druzdzel, M.J. and Flynn, R.R., Decision Support Systems, In: Kent, A., Ed., Encyclopedia of Library and Information Science, 2nd Edition, Marcel Dekker, Inc., New York, 2002.

[31] F. Burstein and C. Holsapple, *Handbook on Decision Support Systems 1*. Springer, 2008.

[32] D. Power, F. Burstein, and R. Sharda, "Reflections on the Past and Future of Decision Support Systems: Perspective of Eleven Pioneers," *Decis. Support. Ann. Inf. Syst*. 14, vol. 14, pp. 25–48, 2011.

[33] D. Power, "A Brief History of Decision Support Systems," Decis. Support Syst. - DSSResources, 2003.

[34] L. Buchanan and A. O'Connell, "A Brief History of Decision Making," *Harv. Bus. Rev.*, pp. 32–41, 2006.

[35] P. Finlay, Introducing decision support systems. NCC Blackwell, 1994.

[36] C. Holsapple, "Decisions and Knowledge", F. Burstein and C. Holsapple,(eds), *Handbook on Decision Support Systems 1*. Springer, pp. 21-53, 2008.

[37] S. Alter, Decision support systems: Current practice and continuing challenges. Addison-Wesley; First edition (August 1, 1979), 1980.

[38] F. Filip, C. Zamfirescu, and C. Ciurea, *Computer-Supported Collaborative Decision-Making*, vol. 4., Springer, 2017.

[39] E. Turban, J. E. Aronson, and T.-P. Liang, *Decision Support Systems and Intelligent Systems*, 7th ed. Prentice-Hall, 2004.

[40] D. Power, "What are characteristics of a decision support system?," *DSS News,* vol. 4, no. 7, 2003.

[41] M. Bohanec, "What is Decision Support ?," *Proc. Inf. Soc. IS-2001 Data Min. Decis. Support Action*, pp. 86–89, 2003.

[42] D. Power and R. Sharda, "Model-driven decision support systems: Concepts and research directions," *Decis. Support Syst.*, vol. 43, no. 3, pp. 1044–1061, 2007.

[43] C. Zhengmeng and J. Haoxiang, "A Brief Review on Decision Support System and its Applications," *IT Med. Educ.*, 2011.

[44] J. Grubert, T. Langlotz, S. Zollman, and H. Regenbrecht, "Towards Pervasive Augmented Reality : Context- Awareness in Augmented Reality," *IEEE Trans. Vis. Comput. Graph.*, vol. 23, no. 6, pp. 1706–1724, 2017.

[45] C. Ware, Information Visualization: Perception for Design, 2nd ed., Morgan Kaufmann, 2004.

[46] B. Zhu and H. Chen, "Information Visualization for Decision Support," *in Handbook on Decision Support Systems*, vol 2, F. Burnstein, C. Holsapple, Springer, pp. 699-722, 2008.

[47] T. Munzner, Visualization Analysis and Design, A K Peters, 2016.

[48] C. T. Chen and T.-W. Chang, "Spatially Augmented Reality Design Environment," Innov. Des. Decis. Support Syst. Archit. Urban Plan., pp. 487–499, 2006.

[49] E. González, J. R. L. Benito, and A. S. Gutiérrez, "Augmented Reality System for Training, Assistance and Decision Making in Real Time situations in the Embedded Electronic field," *5th Jt. Virtual Real. Conf. – JVRC 2013*, 2013.

[50] A. Kaklauskas, E. K. Zavadskas, J. Cerkauskas, I. Ubarte, A. Banaitis, M. Krutinis, and J. Naimaviciene, "Housing Health and Safety Decision Support System with Augmented Reality," *Procedia Eng.*, vol. 122, no. Orsdce, pp. 143–150, 2015.

[51] J. Milovanovic, G. Moreau, D. Siret, and F. Miguet, "Virtual and Augmented Reality in Architectural Design and Education: An Immersive Multimodal Platform to Support Architectural Pedagogy," *17th Int. Conf. CAAD Futur.*, 2017.

[52] S. Krakhofer, M. Kaftan, Y. Ikeda, C. M. Herr, D. Holzer, S. Kaijima, and M. J. Kim, "Augmented Reality Design Decision Support Engine for the Early Building Design Stage," Emerg. Exp. Past, Present Futur. Digit. Archit. Proc. 20th Int. Conf. Assoc. Comput. Archit. Des. Res. Asia (CAADRIA 2015) , pp. 231–240, 2015.