Rethinking UX in 3D Cadastral Systems for Inclusive Land Governance

Angélique MONTUWY, Frédéric HUBERT and Willian Ney CASSOL, Canada

Key words: 3D Cadastral Systems, User Experience (UX), Inclusive Land Governance, Stakeholder Engagement

SUMMARY

This article examines how User Experience (UX) is conceptualized and evaluated in the context of 3D cadastral systems, and advocates for a more holistic and inclusive approach to their design. Although 3D cadastres are often promoted as more accessible and engaging for non-expert users, little attention has been paid to how users - whatever their level of expertise - actually experience and interact with these systems. Our literature review reveals that UX is frequently reduced to usability, overlooking non-instrumental dimensions such as aesthetics, symbolism, and user motivations, factors that are essential to inclusive land governance. Moreover, evaluations of 3D cadastral prototypes rarely involve non-expert participants, and interdisciplinary collaborations remain sparse. To bridge these gaps, we propose reframing UX in 3D cadastres around three pillars: the integration of broader experience dimensions, the inclusion of diverse user groups through participatory methods, and the promotion of interdisciplinary design practices. We argue that institutions like the International Federation of Surveyors (FIG) could play a pivotal role in this transformation by promoting cross-disciplinary dialogue and supporting structured citizen engagement in cadastral research and development. Reimagining UX in this way can not only improve system performance and adoption but also enhance the social legitimacy and accessibility of future cadastral infrastructures.

Rethinking UX in 3D Cadastral Systems for Inclusive Land Governance

Angélique MONTUWY, Frédéric HUBERT and Willian Ney CASSOL, Canada

1. INTRODUCTION

Over the past decade, advances in standardized information models, data visualization, and volumetric database management (e.g. Shahidinejad et al., 2024; Gkeli et al., 2020) have laid a solid foundation for three-dimensional (3D) cadastral systems. By moving beyond two-dimensional cadastre, these systems enable more precise modeling and administration of complex property rights regarding underground utilities (Bieda et al., 2020), water bodies (Dubnysta & Krelshteyn, 2018), or multilevel ownership in densely built urban environments (Guo et al., 2013). Consequently, 3D cadastral systems promise to enhance decision-making, foster shared governance, and improve communication with non-expert stakeholders (Stoter et al., 2019; Shojaei et al., 2018). By contributing to make the cadastral information more accessible, they could help deliver tangible societal and economic impacts such as facilitate the property registration process (Aien et al., 2015) or preventing property disputes (Shojaei et al., 2017) as well as playing a pivotal role in building citizen trust, engagement and sense of identity (Enemark et al., 2015) through clear data, easy visualization and robust access control.

However, realizing these promises requires more than technical maturity: it hinges on designing accessible and intuitive 3D cadastral systems that users will engage with positively. To date, user experience (UX) research in 3D cadastral systems has focused predominantly on usability to ensure that spatial and legal information is intelligible and actionable for users with varying technical backgrounds (e.g. Shojaei et al., 2013; Cemellini et al., 2020). Usability (ISO 9241-11, 2018) is defined by three criteria: the effectiveness (accuracy and completeness of achieving a specific task, in a specific context, for a specific user), the efficiency (the resources that are expended in relation to accuracy), and the satisfaction (comfort and pleasantness of use). While critical for 3D cadastral systems, usability focuses on how well users can perform tasks under specified conditions, without addressing why they feel engaged with a system or choose to return. Acceptability broadens usability to include contextual and organizational factors—cost, compatibility, reliability, and social norms (Davis, 1989; Venkatesh & Bala, 2008) and highlight the importance of representations (perceived usefulness and perceived ease of use) as predictors of adoption. However, acceptability as well remains largely instrumental, omitting hedonic and emotional drivers that underpin long-term engagement (Kujala et al., 2011).

By foregrounding subjective and emotional dimensions, UX extends traditional concepts of usability and acceptability. UX research relies on 4 premises (Van der Linden et al., 2025): (1) UX is inherently subjective; (2) UX goes beyond effectiveness and efficiency by incorporating non-instrumental dimensions; (3) UX aims for greater inclusion of emotional reactions; (4) UX is inherently dynamic and evolves over time. Hence, UX design refers to the process of creating systems that are not only functional and efficient (instrumental qualities) but also meaningful to their intended users (non-instrumental qualities) and that drives an emotional response that invite the user to interact with a system over time (Mahlke and Thüring, 2007; Karapanos et al., 2009).

Despite the subjective dimensions investigated in some 3D cadastral system usability studies, regarding either individual preference (e.g., Pouliot et al., 2013) or perception (Grzelka et al., 2023), none delved into the non-instrumental and emotional dimensions of UX, such as aesthetics, symbolism, and motivation. These dimensions are however critical for sustaining participation and achieving true inclusion (Van der Linden et al., 2025; Hodza, 2009), especially when it comes to governance (Goldsmith, 2018). This gap motivates our positioning. In this paper, we call for a holistic rethinking of UX in 3D cadastral systems by embracing both instrumental and non-instrumental dimensions in order to democratize access to land information. We highlight pathways for embedding user-centred approaches into 3D cadastral design workflows. Our goal is to demonstrate how a reimagined UX can serve as a tool for inclusive, transparent, and adaptive land governance and benefiting a diverse array of actors, from landowners and local communities to survey professionals and public officials.

2. USER EXPERIENCE AND 3D CADASTRAL SYSTEMS

This section surveys existing work at the intersection of three-dimensional cadastral systems and UX. We examine (1) the dimensions of UX integrated into current 3D cadastral system development, (2) the methods that are used, and (3) how stakeholder engagement is structured in existing systems. Our aim is to highlight that truly holistic UX perspectives on 3D cadastral systems remain rare by identifying persistent research gaps that underpin our position.

2.1 UX dimensions in 3D cadastral systems

Although user-centred considerations in the development of 3D cadastral systems are not new, most studies tend to equate user experience (UX) with usability, often without a clear or consistent definition of what usability involves. Cemellini et al. (2020) and van Oosterom et al. (2019), for instance, adopt the ISO definition of usability (2018) to evaluate web-based cadastral systems. Their assessments are based on efficiency, effectiveness, and user satisfaction—where satisfaction is defined as the absence of frustration during task completion. Neuville et al. (2020) examined the usability of different 3D viewpoints by measuring users' accuracy and confidence in completing visualization tasks, treating these metrics as proxies for system efficiency and user satisfaction. Similarly, Shojaei et al. (2013) focused on ease of use and learnability, thereby emphasizing the efficiency and effectiveness of 3D visualizations. Other studies, such as those by Wang and Yu (2021) and Seipel et al. (2020), do not explicitly refer to usability but nonetheless gather user opinions while participants perform predefined tasks—suggesting an implicit evaluation of usability. Across these examples, UX is thus primarily reduced to its instrumental dimensions, with little or no attention paid to non-instrumental aspects.

Beyond usability (however it is defined), a few studies have considered additional UX dimensions that introduce a degree of subjectivity. For example, Pouliot et al. (2013) explored the preferences of notaries and perceptions of the helpfulness of various 3D visualization modalities, while Grezlka et al. (2023) examined how the background of users influence their visual perception of 3D cadastral representations. Accessibility is also addressed in studies such as Cemellini et al. (2020) and Shojaei et al. (2013), particularly regarding web-based

platforms. Seipel et al. (2010) mentioned the feeling of being foreign to the system and the necessity of developing skills for the use of 3D visualisation that could limit the acceptability of such systems. However, these dimensions largely remain within the instrumental realm. Non-instrumental qualities—such as aesthetic appeal, immersion, or emotional engagement elicited by 3D visualizations (van Lammeren et al., 2010)—are almost entirely absent from current system designs, despite their potential to foster deeper user involvement and understanding in complex spatial contexts.

2.2 Evaluation methods

UX in 3D cadastral systems—predominantly limited to its instrumental aspects—is most often assessed through semi-structured interviews and questionnaires administered while participants interact with functional prototypes. The development of such prototypes is central to many studies, including those by Grzelka et al. (2023), Wang and Yu (2021), Cemellini et al. (2020), Seipel et al. (2020), and Shojaei et al. (2015). These prototypes enable researchers to observe task performance under controlled conditions that approximate professional scenarios, thereby facilitating targeted usability evaluations. However, building such systems requires considerable development effort. To mitigate this, Pouliot et al. (2014) opted for a more lightweight approach by using video simulations of a 3D cadastral visualization tool, allowing them to assess core usability metrics without the need for a fully operational prototype.

Questionnaires play a central role in UX evaluation. Some studies employ standardized tools, such as the Small Usability Questionnaire used by Shojaei et al. (2018), while others develop custom instruments tailored to the specific system under investigation (e.g., Cemellini et al., 2020; Neuville et al., 2020; Wang et al., 2016; Elizarova et al., 2012). These questionnaires are often distributed via online platforms like Google Forms (e.g., Wang et al., 2016; Shojaei et al., 2015) and completed either remotely or in the presence of a facilitator (e.g., Grzelka et al., 2023). In addition, semi-structured interviews are frequently used to gather in-depth qualitative feedback (Seipel et al., 2020; Håkansson, 2019; Pouliot et al., 2014, 2013), either as standalone methods or in combination with questionnaires (e.g., Wang and Yu, 2021). While interviews provide a more nuanced understanding of user perceptions, they typically involve smaller samples of individuals drawn from relevant professional communities.

2.3 End users participation

User involvement is frequently cited as a key component in gathering system requirements (e.g., Cemellini et al., 2020; Shojaei et al., 2013). In practice, however, users are most often involved only during the testing phase—once the core features of the system have already been defined (Elizarova et al., 2012; Shojaei et al., 2018). Only a few studies integrate users throughout both the requirements gathering and evaluation phases, such as those by Wang and Yu (2021) and Håkansson (2019), which point toward more participatory design approaches.

Although the importance of including non-expert users is acknowledged (e.g., Shojaei et al., 2013), the majority of studies continue to focus on participants with professional experience in land administration or cadastral systems. For example, Shojaei et al. (2015) evaluated their prototype with land surveyors, plan examiners, and cadastral experts. Seipel et al. (2020) involved professionals from registration and planning departments, as well as real estate

specialists. Pouliot et al. (2013), for their part, focused on notaries with a specific interest in 3D visualization. Notably, some studies do attempt to include non-expert users. Wang and Yu (2021), for instance, highlight the value of involving lay property owners in China, noting that graphic representations—currently in 2D—are an essential part of property registration documents issued to owners. Grzelka et al. (2023) also involved students with and without a background in geodetic sciences, in order to explore how disciplinary expertise affects usability perceptions.

3. DECLARATION OF POSITION

In this paper, we argue that systematically integrating all dimensions of User Experience (UX) throughout the lifecycle of 3D cadastral systems is essential for these platforms to fulfill their promise of inclusive, transparent, and adaptive land governance.
Our position is grounded in three core tenets:

- Recognition of Non-Instrumental Qualities: Beyond efficiency and accuracy, 3D cadastral systems must incorporate dimensions such as aesthetic appeal, emotional resonance, perceived trustworthiness, and cultural symbolism. These qualities foster sustained user engagement and inclusion, particularly among non-expert users.
- Early and Ongoing Stakeholder Engagement: Authentic co-creation with diverse stakeholders such as landowners, community leaders, surveying professionals, and public officials, should occur from the earliest stages of system design. This ensures that solutions are responsive to real-world needs, contexts, and values.
- Interdisciplinary Collaboration by Design: Geospatial experts, UX designers, legal scholars, and social scientists must work in integrated teams, sharing common frameworks and goals. Only such collaboration can yield cadastral tools that are both technically robust and meaningfully human-centred.

By advancing these tenets, we call upon researchers, system developers, and policymakers to shift from tokenistic or late-stage user involvement toward a genuinely holistic UX approach. Only then can 3D cadastral systems truly democratize access to land information, cultivate trust, and empower all stakeholders—as envisioned by the cadastral community (Enemark et al., 2015).

4. INTERDISCIPLINARY DISCUSSION

The following discussion draws on the diversity of disciplinary backgrounds of our team, ranging from land governance to HCI in geomatics and design, to reflect on the limitations of current approaches and propose ways to foster more inclusive, meaningful, and context-aware cadastral systems. We focus on three key aspects that emerged from our review work: (1) the need of conceptual shift from usability to a broader understanding of user experience; (2) the importance of greater diversity in user engagement and co-design; and (3) the crucial role of research diversity in shaping meaningful interactions with cadastral technologies.

4.1 From usability to user experience

As highlighted in our review, most research on 3D cadastral systems reduces UX to its instrumental dimensions, primarily through the lens of usability. While this focus has contributed valuable insights, we argue that it is insufficient for supporting the use of 3D cadastral systems in inclusive, transparent, and adaptive land governance.

A first argument concerns the assumed benefits of 3D visualizations. As noted by Seipel et al. (2020), 3D models enhance spatial understanding and support better visualization of complex territorial arrangements. Much of the existing research on usability has thus focused on optimizing these visualizations to improve task performance and accessibility. However, as examples such as Ryan (2007) reminds us, clearer representations do not necessarily lead to better or faster decision-making compared to 2D ones. This gap highlights the need to explore additional dimensions of 3D systems beyond clarity and comprehension. For instance, Van Lammeren et al. (2010) compared affective responses to different types of visual representations—colored raster cells, 2D icons, and 3D icons—and found that 3D icons elicited the strongest emotional reactions and most positive perceptions of environmental quality. Although these findings stem from environmental visualization rather than cadastral contexts, they suggest that emotional responses to 3D representations could deserve closer attention in cadastral applications as well.

The relation between 3D and emotions lead to our second argument, that emphasizes the role of aesthetics and emotion in how users perceive value and trust in digital systems. Despite extensive work on improving visualization in 3D cadastral interfaces (e.g., Shojaei et al., 2013), the aesthetic dimension of this visualization is often overlooked. Yet aesthetics strongly influences the perceived value of products and systems (Shi et al., 2021) and users' trust in them (Weinstock et al., 2012). In the context of land governance, where systems must convey legitimacy and institutional credibility, this omission is particularly problematic. A visually coherent and appealing interface can reinforce perceptions of reliability, transparency, and fairness—attributes essential for inclusive governance. Focusing on usability that interpret satisfaction as the absence of frustration (as in Cemellini et al., 2020) underestimates the role of non-instrumental dimensions such as aesthetics in shaping user engagement. Satisfaction, as van der Linden et al. (2025) argue, is fundamentally linked to non-instrumental dimensions such aesthetic appreciation, emotional engagement, and symbolic resonance. Moreover, several research works conducted by the French National Institute of Geographic and Forest Information (IGN) offer valuable insights for the design of aesthetic 3D geovisualization. Based on 2D cartographic representations, the authors defined new approaches of map representation inspired from Pop Art (Christophe & Hoarau, 2012) and aesthetic paradigms (Christophe et al., 2016). These approaches aim to visually customize the content of map and to improve the understanding of each final user with an element of aesthetic appeal.

Our third argument is that cadastral systems never operate in a vacuum. They are embedded within broader socio-economic, cultural, and technological ecosystems that profoundly shape users' expectations, values, and interpretations. While 3D cadastral systems acknowledge differences in legal frameworks or data structures across countries (e.g., Elizarova et al., 2012), they less frequently account for organizational or cultural barriers that may hinder the uptake of 3D information by end users (Wong and Ellul, 2018). This becomes particularly

important when considering the use of these systems for participatory land governance. For example, users today are regularly exposed to high-quality 3D visualizations in fields like gaming or digital media, which may elevate their standards for what appears trustworthy, engaging, or professionally credible. Many 3D cadastral systems, however, offer relatively limited rendering capabilities or visual realism, potentially falling short of these rising expectations. Similar challenges are already being addressed in related fields such as 3D GIS (Iordanidis & Georgiadis, 2025), suggesting that the cadastral domain could benefit from cross-disciplinary insights. This also raises important questions about how to negotiate trade-offs between visual quality and data fidelity in cadastral systems—particularly when communicating complex spatial information to diverse user groups.

Hence, a shift from usability to full-spectrum UX therefore calls for a redefinition of what counts as meaningful evaluation**.** It requires integrating not only task performance, but also perceived usefulness, aesthetic value, emotional resonance, and social meaning—acknowledging users as whole people, not just task performers.

4.2 From testing to collaborative design

Our review reveals that users are predominantly framed as professional testers in current research on 3D cadastral systems. Evaluation is typically limited to performance-based tasks and conducted through directive or semi-directive methods, such as questionnaires or interviews. This narrow framing raises several concerns and prompts us to advocate for a shift toward more participatory and collaborative design approaches to support more meaningful user experiences.

First, user needs are often inferred from existing literature and filtered through a predominantly professional lens. This tends to reduce users to predefined roles and tasks, with limited attention paid to the broader contextual and situated nature of their activities—elements that are essential to understanding user experience (Daniellou & Rabardel, 2005). While some studies acknowledge user heterogeneity (e.g., Seipel et al., 2020), they remain largely task-centric. As a result, there is little space for the emergence of unexpected needs or uses outside the designers' original assumptions. This issue is compounded by directive evaluation methods, which constrain exploration beyond predefined scenarios. However, research such as Wong and Ellul (2018), which uses elicitation techniques in the context of 3D GIS, shows that even with small samples (eight participants, in their case), it is possible to uncover expectations that extend beyond task efficiency—such as the importance of routine or concerns about learning curves. Similarly, Roth (2015) explores the work practices of cartographers to highlight how UX evolves beyond strict functionality. Milyana et al. (2021), use tools such as the Actor-Network Theory diagrams to explore the complexity of the interactions between humans and GIS. While in-depth need-finding may appear time-consuming or resource-heavy, lightweight approaches such as persona development (e.g., Hixson & Parrott, 2021) can help cultivate a more nuanced and inclusive understanding of users.

Second, although the importance of opening cadastral systems to non-expert users and citizens is widely acknowledged (Pouliot et al., 2018; Enemark et al., 2015; Shojaei et al., 2013)—especially in the context of inclusive land governance—, this population remains

largely absent from the design and evaluation processes. With the notable exception of Wang and Yu (2021), most research focuses on technical development and professional users. Yet insights from e-governance highlight that technology-driven initiatives frequently fail when they neglect citizen needs and expectations (Bertot et al., 2008). Integrating iterative design methods such as low-fidelity prototyping or wireframing (e.g., Pouliot, 2013) could enable quicker feedback loops and foster stronger alignment with citizen expectations. Recent advances in UX design for public digital services also underscore the importance of long-term user engagement, trust-building, and attention to demographic diversity as critical components of meaningful UX (Aldrees & Gracanin, 2023). Establishing citizen advisory boards or developing partnerships with local communities could thus represent valuable strategies to better integrate UX into 3D cadastral systems.

Another dimension of citizen involvement concerns data production itself. Beyond institutional survey datasets, communities are increasingly generating land-related information through drone imagery, volunteered geographic information, or mobile-based mapping. While the reliability and accuracy of these sources vary, their inclusion can enrich 3D cadastral platforms by offering a more nuanced and context-sensitive representation of land tenure. From a UX perspective, this requires interfaces and workflows that make data provenance transparent, enabling users to clearly distinguish between official, community-based, and sensor-derived information, while still benefiting from their combined value in visualization and decision-making.

Third, although accessibility is occasionally addressed in 3D cadastre research (e.g, Cemellini et al., 2018), it is mostly framed as a matter of technological access. Most systems offer limited room for personalization (except e.g. Seipel et al., 2020 for transparency). If public-facing 3D cadastral visualizations are to become widespread, they will need to accommodate the diverse perceptual and cognitive profiles of users—an issue raised by Grzelka et al. (2023), who caution against the use of visual variables that are predominantly design for expert users. A lack of personalization of interfaces and interactions could lead to lower perceived ease of use among non-expert audiences. This reinforces the need for broader and more inclusive testing—across both professional and non-professional user groups—with attention to diverse cognitive and perceptual abilities. It also calls for the exploration of new visualization and interaction techniques (as recently stated by Meliana et al. 2024), the use of open-ended research methods (e.g., elicitation interviews, co-design workshops) and a stronger commitment to designing not just for usability, but for acceptability and meaningful experience across a wide variety of human contexts.

4.3 From disciplinary to interdisciplinary research

Research on 3D cadastral systems is predominantly driven by experts in geospatial technologies. While such expertise is indispensable, it can also constrain the scope of inquiry when conducted within disciplinary silos. Designing systems that are not only technically robust but also inclusive, emotionally resonant, and socially legitimate requires opening up to other disciplinary perspectives—particularly from design studies, psychology, sociology, and communication theory. The importance of interdisciplinarity has already been acknowledged in cartography (Schiewe, 2021) and in UX research (Yu et al., 2020) yet remains underexplored in the context of cadastral systems.

Public service design research—especially in the fields of e-government and digital civic platforms—offers valuable frameworks for participatory methods, trust-building, and sustained user engagement (Aldrees & Gracanin, 2023; Trischler & Westman Trischler, 2021). Cognitive psychology can contribute critical insights into how diverse populations interpret spatial and legal information (Montello, 2009). Similarly, work in Human-Data Interaction (Victorelli et al., 2020) can help interrogate the ethical, social, and emotional dimensions of 3D visualizations—dimensions which are often overlooked despite their relevance for inclusive land governance (Pouliot et al., 2018).
This paper itself illustrates that interdisciplinary approaches in the 3D cadastre field are not only possible, but essential. Far from diluting technical expertise, interdisciplinary collaboration enriches the design and evaluation of cadastral systems, and opens the door to more responsive, equitable, and meaningful digital infrastructures for land governance.

5. PERSPECTIVES

The transformation of 3D cadastral systems into inclusive and accessible tools of governance will not come from technical innovation alone. It demands institutional leadership and collective action to reshape how these systems are designed, evaluated, and governed. In this context, we think that the International Federation of Surveyors (FIG) is uniquely positioned to lead a new chapter in 3D cadastral development by championing interdisciplinary collaboration and user participation at a global scale.

First, the FIG can play a pivotal role in promoting interdisciplinary research practices within the geospatial community. By actively encouraging partnerships between surveyors, UX designers, data scientists, and social scientists, FIG can help shift the framing of cadastral systems—from technical products to participatory tools that must support not only usability, but also transparency, trust, and long-term engagement. This could involve updating existing FIG working groups or commissions (e.g., Commission 3 on Spatial Information Management or Commission 7 on Cadastre and Land Management) to include experts in design studies and human-centered computing, and organizing dedicated events focused on user experience in land governance.

Second, the FIG could lead by example in institutionalizing citizen participation in 3D cadastre research and development. While many pilot projects acknowledge the importance of non-expert users, they often lack the structure and resources to meaningfully engage them. FIG could initiate and coordinate the creation of international advisory panels composed of citizen users—farmers, tenants, informal settlers, urban residents, etc.—who could participate in co-design activities, scenario testing, and feedback cycles. These panels could work in collaboration with local surveying authorities, academic institutions, and open-source development initiatives, helping to ensure that cadastral innovations are relevant, accessible, and context-sensitive.

Furthermore, FIG's global reach allows it to facilitate knowledge exchange across countries and regions**,** sharing case studies, tools, and lessons learned in citizen-centered cadastral

design. This would be particularly valuable in low- and middle-income countries, where informal tenure systems, limited digital access, and administrative fragmentation create specific UX challenges that are too often overlooked in mainstream technical development.

6. CONCLUSION

This paper has argued for a holistic rethinking of User Experience (UX) in 3D cadastral systems as a necessary step toward inclusive and adaptive land governance. Our review highlights that while 3D systems are maturing technologically, they remain conceptually limited by narrow definitions of usability and restricted models of stakeholder participation. To fulfill their promise, these systems must be designed not only to perform efficiently but also to resonate emotionally, communicate clearly, and reflect the diverse needs and values of all users. We call for a paradigm shift: from usability-focused evaluation to experience-centered design; from passive end-user testing to active co-creation; from siloed disciplinary development to interdisciplinary collaboration. Institutions such as the FIG can play a central role in enabling this transformation by fostering new alliances, creating spaces for non-expert engagement, and elevating UX as a fundamental dimension of cadastral innovation. In doing so, 3D cadastral systems can become more than technical tools—they can become instruments of empowerment, recognition, and justice in the management of land and property rights**.**

REFERENCES

Aien, A., Rajabifard, A., Kalantari, M., Shojaei, D. 2015. Integrating Legal and Physical Dimensions of Urban Environments. *Int. J. Geo-Inf. 4*, 1442–1479. https://doi.org/10.3390/ijgi4031442

Aldrees, A. & Gracanin, D. 2023. UX in E-government Services for Citizens: A Systematic Literature Review. Journal of User Experience, 18(3), 133-169. https://uxpajournal.org/ux-in-e-government-services-for-citizens-a-systematic-literature-review/

Bertot, J. C., Jaeger, P. T., & McClure, C. R. 2008. Citizen-centered e-government services: Benefits, costs, and research needs. *Proceedings of the 9th Annual International Digital Government Research Conference,* 137–142. https://doi.org/10.1145/1367832.1367858

Bieda, A., Bydłosz, J., Warchoł, A., & Balawejder, M. 2020. Historical Underground Structures as 3D Cadastral Objects. *Remote Sensing*, *12*(10), 1547. https://doi.org/10.3390/rs12101547

Cemellini, B., van Oosterom, P., Thompson, R., de Vries, M. 2020. Design, development and usability testing of an LADM compliant 3D Cadastral prototype system. *Land Use Policy*, 98:104418. https://doi.org/10.1016/j.landusepol.2019.104418

Christophe, S., & Hoarau, C. 2012. Expressive Map Design Based on Pop Art: Revisit of Semiology of Graphics?. *Cartographic Perspectives, (73),* 61–74. https://doi.org/10.14714/CP73.646

Christophe, S., Duménieu, B., Turbet, J., Hoarau, C., Mellado, N., Ory, J., Loi, H., Masse, A., Arbelot, B., Vergne, R. and Brédif, M.. 2016. Map style formalization: Rendering techniques extension for cartography. *In Expressive 2016 the joint symposium on computational aesthetics and sketch-based interfaces and modeling and non-photorealistic animation and rendering (pp. 59-68)*. The Eurographics Association.

Daniellou, F. and Rabardel, P. 2005. Activity-oriented approaches to ergonomics: some traditions and communities. *Theoretical Issues in Ergonomics Science, 6(5),* 353-357. https://doi.org/10.1080/14639220500078351

Davis, F. D. 1989. Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, 13 (3): 319–340. https://doi.org/10.2307/249008

Dubnytska, M. & Krelshteyn, P. 2018. 3D Cadastre as a Tool for Water Bodies Account. *17th Conference in GeoDinformatics*. 14-17 May, Kiev, Ukraine.

Elizarova, G., Sapelnikov, S., Vandysheva, N., Pakhomov, S., Van Oosterom, P., de Vries, M., Stoter, J., Ploeger, H., Spiering, B., Wouters, R., Hoogeven, A., Penkov, V. 2012. Russian-Dutch Project "3D Cadastre Modelling in Russia". *3 rd International Workshop on 3D Cadastres: Developments and Practices 25-26 October 2012*, Shenzhen, China. Russian-Dutch%20Project%20"3D%20Cadastre%20Modelling%20in%20Russia".pdf

Enemark, S., de Zeeuw, K., Williamson, I. P., Jones, B. A., van Oosterom, P., Lemmen, C., Lawrence V, Blake, C. 2015. Cadastre in a Changing World: Issues and directions. *Coordinates*, XI(4), April. https://mycoordinates.org/cadastre-in-a-changing-world-issues-and-directions/

Gkeli, M., Potsiou, C., Ioannidis, C. 2020. A technical solution for 3D crowdsourced cadastral surveys. *Land Use Policy* 98:104419. https://doi.org/10.1016/j.landusepol.2019.104419

Goldsmith, S. 2018. How the User Experience (UX) can build greater trust in local government. *Urban Policy 2018*. Manathan Institute. https://media4.manhattan-institute.org/sites/default/files/MI_Urban_Policy_2018.pdf#page=155

Grzelka, K., Bieda, A., Bydlosz, J., Kondak, A. 2023. Visual Perception of Property Rights in 3D. *ISPRS Int. J. Geo-Inf*, *12*(4), 164; https://doi.org/10.3390/ijgi12040164

Guo R, Li L, Ying S, Luo P, He B, Jiang R 2013. Developing a 3D cadastre for the administration of urban land use: A case study of Shenzhen, China. *Computers, Environment and Urban Systems* 40:46–55. https://doi.org/10.1016/j.compenvurbsys.2012.07.006

Håkansson, L. 2019. Visualizing cadastral parcels for surveyors using handheld Augmented Reality. *Bachelor Thesis, Malmö University, Sweden*. https://www.diva-portal.org/smash/get/diva2:1480790/FULLTEXT01.pdf

Hixson, T. and Parrott, J. 2021. Using UX Personas to Improve Library GIS and Data Services. *Weave: Journal of Library User Experience,* 4(2). https://doi.org/10.3998/weaveux.221

Hodza, P. 2009. Evaluating User Experience of Experiential GIS. *Transactions in GIS*, 13:503-525. https://doi.org/10.1111/j.1467-9671.2009.01176.x

International Organization for Standardization (ISO) 2018. 9241-Ergonomics of human-system interaction — Part 11: Usability: Definitions and concepts.

Iordanidis, C., Georgiadis, C. K. 2025. Efficient Visualization of 3D Urban Environments in the Metaverse by Integrating GIS and Unreal Engine. *8th International Conference on Information and Computer Technologies (ICICT), 14-16 March, Hawaii-Hilo, HI, USA*. https://doi.org/10.1109/ICICT64582.2025.00057

Karapanos, E., Zimmerman, J., Forlizzi, J., Martnes, J.-B. 2009. User Experience Over Time: An Initial Framework. *CHI '09: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 729 – 738. https://doi.org/10.1145/1518701.1518814

Kujala, S., Roto, V., Väänänen-Vainio-Mattila, K., and Sinnelä, A. 2011. Identifying hedonic factors in long-term user experience. *In Proceedings of the 2011 Conference on Designing Pleasurable Products and Interfaces (DPPI '11),* 17:1–8. https://doi.org/10.1145/2347504.2347523

Mahlke, S., Thüring, M. 2007. Studying antecedent of emotional experiences in interactive contexts. *ACM CHI 2007 Proceedings, Emotion & Empathy Session*. https://doi.org/915-918. 10.1145/1240624.1240762

Meliana, I., Hajji, R., Shojaei, D. 2024. Exploring Spatial Interaction and Visualization Paradigms for 3D Cadastral Visualization. *19th 3D GeoInfo Conference 2024, 1–3 July 2024, Vigo, Spain*. https://doi.org/10.5194/isprs-annals-X-4-W5-2024-237-2024

Milyana, N. A. N, Van Loenen, B., Korthals Altes, W., Ploeger, H. 2021. 4D Musrenbang: Designing User Experience (UX) to Support Public Participation in Spatial Planning for Indonesia. *7th International FIG 3D Cadastre Workshop, 11-13 October 2021, New York, USA.* https://doi.org/10.4233/uuid:b00ca7b9-a480-4752-b12b-f7337b62e262

Montello, D. R. 2009. Cognitive Research in GIScience: Recent Achievements and Future Prospects. *Geography Compass, 3(5),* 1824-1840. https://doi.org/10.1111/j.1749-8198.2009.00273.x

Neuville, R., Pouliot, J., and Billen, R. 2020. 3D viewpoint optimization of topological relationships: application to 3D cadastre for visual easement validation. *ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., VI-4/W1-2020,* 135–142. https://doi.org/10.5194/isprs-annals-VI-4-W1-2020-135-2020

Pouliot, J., Wang, C., Fuchs, V, Hubert, F., Bédard, M. 2013. Experiments with notaries about the semiology of 3d cadastral models. *ISPRS 8th 3DGeoInfo Conference & WG II/2 Workshop, 27 – 29 November 2013, Istanbul, Turkey*. https://doi.org/10.5194/isprsarchives-XL-2-W2-53-2013

Pouliot, J., Wang, C., Hubert, F., Fuchs, V. 2014. Empirical Assessment of the Suitability of Visual Variables to Achieve Notarial Tasks Established from 3D Condominium Models. In Isikdag, U. (Ed.). *Innovations in 3D Geo-Information,* Springer.

Pouliot, J., Ellul, C., Hubert, F., Wang, C., Rajabifard, A., Kalantari, M., Shojaei, D., Atazadeh, B., van Oosterom, P., de Vries, M. 2018. 3D Cadastres Best Practices, Chapter 5: Visualization and New Opportunities. *FIG Congress. Istanbul, Turkey, May 6–11*. https://pure.tudelft.nl/ws/portalfiles/portal/51563860/TS04C_pouliot_ellul_et_al_9658.pdf

Ryan, R. A. 2007. Enhancing 3D Models with Urban Information: A Case Study Involving Local Authorities and Property Professionals in New Zealand: Quantifying the Benefit of 3D over Alternative 2D systems. *MSc Thesis, Victoria University of Wellington, New Zealand*.

Schiewe, J. 2021. The need for disciplinarity, interdisciplinarity and scientific societies - the cartographic perspective. *Geo-spatial Information Science, 24*. https://doi.org/10.1080/10095020.2020.1863748

Seipel, S., Andrée, M., Larsson, K. *et al.* Visualization of 3D Property Data and Assessment of the Impact of Rendering Attributes. 2020. *Journal of geovisualization and spatial analysis* 4, 23. https://doi.org/10.1007/s41651-020-00063-6

Shahidinejad, J., Kalantari, M., & Rajabifard, A. 2024. 3D Cadastral Database Systems—A Systematic Literature Review. *ISPRS International Journal of Geo-Information*, *13*(1), 30. https://doi.org/10.3390/ijgi13010030

Shi, A., Huo, F., Hou, G. 2021. Effects of Design Aesthetics on the Perceived Value of a Product. Frontiers in Psychology, 12:670800. https://doi.org/10.3389/fpsyg.2021.670800

Shojaei, D., Kalantari, M., Bishop, I.D., Rajabifard, A., Aien, A. 2013. Visualization requirements for 3D cadastral systems. *Computers, Environment and Urban Systems,* 41:39-54. https://doi.org/10.1016/j.compenvurbsys.2013.04.003

Shojaei, D., Olfat, H., Quinones Faundez, S., Kalantari, M., Rajabifard, A., Briffa, M. 2017. Geometrical data validation in 3D digital cadaster—A case study for Victoria, Australia. *Land Use Policy J. 68*, 638–648. https://doi.org/10.1016/j.landusepol.2017.08.031

Shojaei, D., Olfat, H., Rajabifard, A., Briffa, M. 2018. Design and Development of a 3D Digital Cadastre Visualization Prototype. *ISPRS Int. J. Geo-Inf. 7*(10), 384. https://doi.org/10.3390/ijgi7100384

Stoter, J., Ho, S., & Biljecki, F. 2019. Considerations for a contemporary 3D cadastre for our times. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-4/W15, 81–88*. https://doi.org/10.5194/isprs-archives-XLII-4-W15-81-2019.

Trischler, J & Westman Trischler, J. 2021. Design for experience – a public service design approach in the age of digitalization. *TFO Collections*, 1251–1270. https://doi.org/10.1080/14719037.2021.1899272

Van der Linden, J., Hellemans, C., Amadieu, F., Vayre, E. & van de Leemput, C. 2025. User Experience (UX) with Mobile Devices: A Comprehensive Model to Demonstrate the Relative Importance of Instrumental, Non-Instrumental, and Emotional Components on User Satisfaction. *International Journal of Human–Computer Interaction,* 41:8, 4516-4527, https://doi.org/10.1080/10447318.2024.2352210

Van Lammeren, R., Houtkamp, J., Colijn, S., Hilferink, M., Bouwman, A. 2010. Affective appraisal of 3D land use visualization. *Computers, Environment and Urban Systems,* 34(6), 465-475. https://doi.org/10.1016/j.compenvurbsys.2010.07.001

Van Oosterom, P., de Vries, M. Cemellini, B., Thompson, R., Shnaidman, A. 2019. Results of the Public Usability Testing of a Web-Based 3D Cadastral Visualization System. *FIG Working Week 2019 Geospatial information for a smarter life and environmental resilience*. https://www.fig.net/resources/proceedings/fig_proceedings/fig2019/papers/ts06c/TS06C_van_oosterom_de_vries_et_al_10082_abs.pdf

Venkatesh, V. & Bala, H. 2008. Technology Acceptance Model 3 and a Research Agenda on Interventions. *Decision Sciences*, 39 (2): 273–315. https://doi.org/10.1111/j.1540-5915.2008.00192.x

Victorelli, E., Z., Dos Reis, J. C., Hornung, H., Prado, A., B. 2020. Understanding human-data interaction: Literature review and recommendations for design. *International Journal of Human-Computer Studies, 134*, 13-32. https://doi.org/10.1016/j.ijhcs.2019.09.004

Wang, C., Pouliot, J., Hubert, F., 2016. How users perceive transparency in the 3D visualization of cadastre: testing its usability in an online questionnaire. GeoInformatica 21(3), 599–618. https://doi.org/10.1007/s10707-016-0281-y

Wang, C., & Yu, C.-B. 2021. Design, Development and Applicability Evaluation of a Digital Cartographic Model for 3D Cadastre Mapping in China. *ISPRS Int. J. Geo-Inf.*, *10*(3), 158. https://doi.org/10.3390/ijgi10030158

Weinstock, A., Oron-Gilad, T., Parmet, Y. 2012. The effect of system aesthetics on trust, cooperation, satisfaction and annoyance in an imperfect automated system. *Work (Reading, Mass.)*, *41 Suppl 1*, 258–265. https://doi.org/10.3233/WOR-2012-0166-258

Wong, K. And Ellul, C. 2018. User requirements gathering for a national 3D mapping product in the United Kingdom. ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., IV-4/W6, 89–96. https://doi.org/10.5194/isprs-annals-IV-4-W6-89-2018

Yu, F., Ruel, L., Tyler, R., Xu, Q., Cui, H., Karanasios, S., Nguyen, B. X., Keilbach, A., Mostafava, J. 2020) Innovative UX Methods for Information Access Based on Interdisciplinary Approaches: Practical Lessons from Academia and Industry. *Data and Information Management, 4(1)*, 74-80. https://doi.org/10.2478/dim-2020-0004

BIOGRAPHICAL NOTES

Angélique Montuwy is Associate Professor of User Experience (UX) Design at the École de technologie supérieure (ÉTS) in Montréal. Her expertise lies in spatial cognition, educational design, multisensory interactions and participatory methods. Her work focuses on designing of accessible, inclusive and participative geospatial solutions for communities' empowerment.

Frédéric Hubert is Associate Professor in the Department of Geomatics at Université Laval. His expertise includes GIS, 2D and 3D geovisualization, noise mapping, geospatial intelligence, and web-based geospatial services. His work focuses on developing computational approaches for the representation and analysis of spatial data.

Willian Ney Cassol is Assistant Professor in the Department of Geomatics at Université Laval in Québec city. His expertise covers photogrammetry, LiDAR, and hydrospatial applications, with a focus on coastal morpho-sedimentary dynamics and seabed characterization. He develops innovative methods for data acquisition and processing, including the use of low-cost platforms for surveying and coastal modeling.

CONTACTS

Willian Ney Cassol
Université Laval
1055, Avenue du Séminaire
Québec, G1V 0A6
CANADA
E-mail: willian-ney.cassol@scg.ulaval.ca
Website: https://reper3d.ffgg.ulaval.ca/