



Research article

Digital tools for brownfield redevelopment: Stakeholder perspectives and opportunities

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ABSTRACT

Brownfield redevelopment is a complex process often involving a wide range of stakeholders holding differing priorities and opinions. The use of digital systems and products for decision making, modelling, and supporting discussion has been recognised throughout literature and industry. The inclusion of stakeholder preferences is an important consideration in the design and development of impactful digital tools and decision support systems. In this study, we present findings from stakeholder consultation with professionals from the UK brownfield sector with the aim of informing the design of future digital tools and systems. Our research investigates two broad themes; digitalisation and the use of digital tools across the sector; and perceptions of key brownfield challenge areas where digital tools could help better inform decision-makers. The methodology employed for this study comprises the collection of data and information using a combination of interviews and an online questionnaire. The results from these methods were evaluated both qualitatively and quantitatively. Findings reveal a disparity in levels of digital capability between stakeholder groups including between technical stakeholder types, and that cross-discipline communication of important issues may be aided by the development of carefully designed digital tools. To this end, we present seven core principles to guide the design and implementation of future digital tools for the brownfield sector. These principles are that future digital tools should be: (1) Stakeholder driven, (2) Problem centred, (3) Visual, (4) Intuitive, (5) Interactive, (6) Interoperable, and (7) Geospatial data driven.

1. Introduction

Deindustrialisation across the UK, Europe and other parts of the world has led to the abandonment of former industrial sites, or *brownfields*, which pose environmental, social, and economic redevelopment challenges for countries and communities (Naidu et al., 2021). Brownfields can be usefully described as: “sites that have either been affected by the former uses of the site and the surrounding land, are derelict or underused; or have real or perceived contamination problems; and are mainly in developed urban areas and require intervention to bring them back to beneficial use” (CABERNET, 2006).

In the UK, it is recognised that brownfield sites represent a significant underutilised housing resource (MHCLG, 2020). Under the Town and Country Planning (Brownfield Land Register) Regulations 2017, local

authorities are required to create and maintain a Brownfield Register for all brownfield sites that are available for housing development, irrespective of their planning status (MHCLG, 2017), meaning that the Brownfield Register sites are only a sub-set of all brownfield land in the UK. The Campaign to Protect Rural England (CPRE) (a charity lobbying to prevent unnecessary development on greenfield sites) estimates that current sites on Brownfield Registers across England have the capacity to provide space for a minimum of 1,077,292 dwellings (CPRE, 2020). In the 2020 spending review, the UK government released four-hundred million pounds (£400 m) as part of the Brownfield Land Release Fund (BLRF) under the National Home Building Fund (OGP, LGA & MHCLG, 2021). This release of funds demonstrates the UK government's commitment to developing brownfield sites as a priority to meet house building targets.

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The specific planning and development process for brownfield sites can depend on project or site-specific requirements as well as local or national regulations. Fig. 1 (from (Hammond et al., 2021)) shows the typical process for redeveloping brownfield sites and managing the potential risk posed by contaminated land, highlighting the relationships between land use planning scale, development stage, uncertainty in decision making, and data needs.

Making decisions around land use requires consideration of many different factors in a structured manner to allow the best possible decision to be undertaken (Guarini et al., 2018). Deciding whether brownfield land is safe and suitable for its intended use requires consideration of environmental (e.g. pollution) social (e.g. proximity to infrastructure) and economic (e.g. house prices) factors as well as attitudes of stakeholders including the public toward the redevelopment project (Loures and Vaz, 2018). The complex interactions between ground issues caused by post-industrial legacy and stakeholder preferences results in the need for a considered strategy when dealing with brownfield redevelopment (CABERNET, 2006; Hammond et al., 2021; Rizzo et al., 2015). Compromise can be difficult to achieve due to a lack of information acquisition and exchange (Alexandrescu et al., 2017; Cappai et al., 2019). The US Environmental Protection Agency (US EPA) defined 5 steps for ‘Successful Brownfield Redevelopment’, focussed around community and stakeholder interaction (US EPA, 2019). Research in both academic literature and industrial guidance has shown that brownfield decision-makers must involve stakeholders within the redevelopment process to ensure a successful and mutually beneficial project (Bartke et al., 2016; Billger et al., 2017; Washbourne et al., 2020).

There are many mechanisms for developers and other brownfield professionals (i.e. consultants, land-use planners) to engage with stakeholders (Rizzo et al., 2015). Firstly, stakeholder engagement led by

the planning system, where stakeholder consultation is required by the national, regional, or local planning policy (MHCLG, 2019). Secondly, project-specific campaigns led by developers and development schemes, where a small circle of stakeholders unique to a certain redevelopment scheme are consulted about their preferences and desires for a project. This is generally achieved through focus groups, workshops, polling and interview-like discussion. Third, large scale stakeholder engagement, where a consultation is carried out by public interest groups, national government, or academics. This usually also includes the involvement of focus groups, workshops, and interviews, but also the use of methods designed to survey a larger number of stakeholders, such as online questionnaires. Stakeholder engagement of this type typically proceeds an investigative project, such as research or the development of a new product (Morgan, 1996), for example, new digital solutions to solve problems identified from stakeholder research. Recent work by Wilson and Tewdwr-Jones (2021) explores stakeholder engagement for planning through digital methods. To encourage engagement and elicit information from a wide group of stakeholders, a multi-level strategy for stakeholder participation could be implemented. This could involve the use of digital and non-digital methods alongside each other, a combination of face-to-face discussion, workshops, and interviews, combined with digital surveys, public polls, and social media engagement campaigns (Wilson and Tewdwr-Jones, 2021).

For the purpose of this research, we have defined digitisation as: ‘the conversion of paper-based or analogue information into digital format’ whereas we define digitalisation as: ‘the use of digital technologies to change and/or improve the way an organisation carries out their operations’.

Digital tools and technology have long been used by decision makers around the world who are involved with urban planning and development. GIS and mapping tools are often used to inform land-use planning

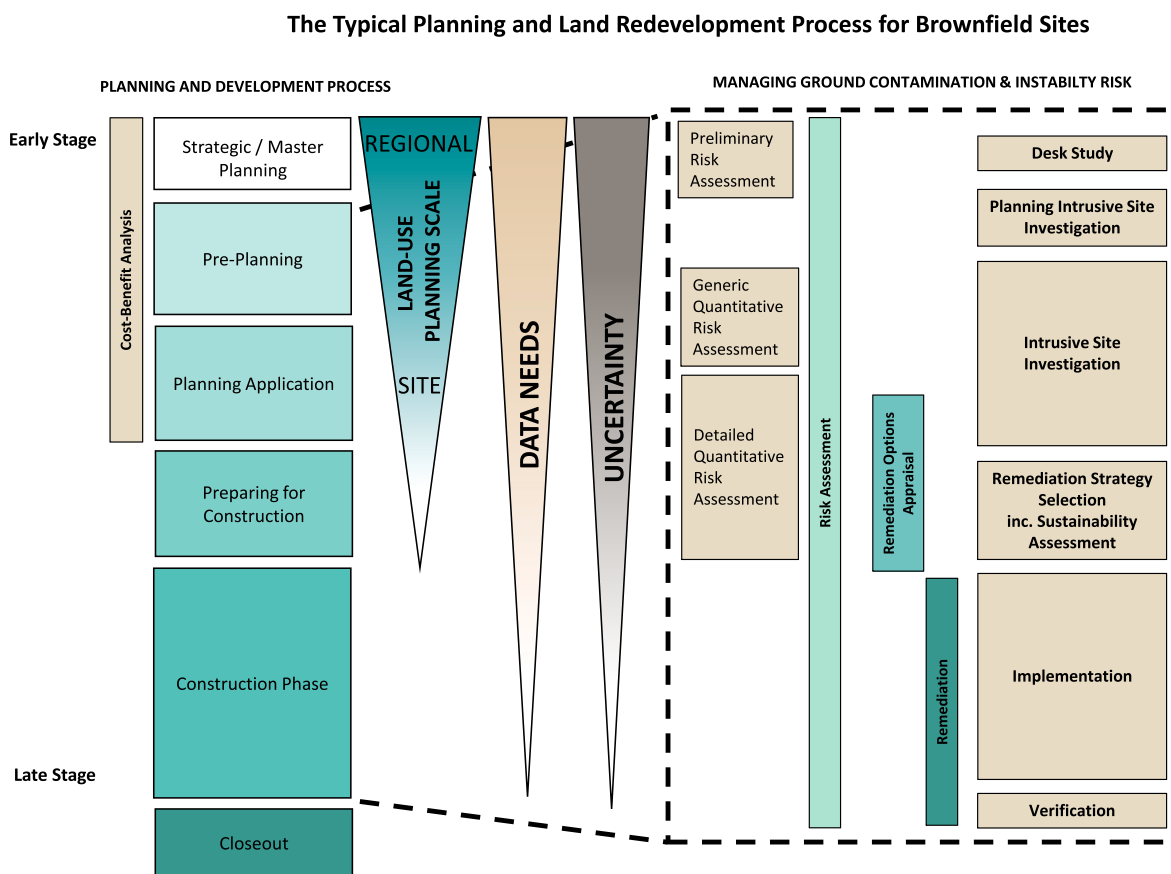


Fig. 1. The typical planning and land development process for brownfield sites indicating the relationship between steps within each domain showing how scale, data and uncertainty reduce over time (Hammond et al., 2021).

in urban areas (Wang et al., 2015). Many tools have been developed to assist the allocation of precious urban land for a variety of uses, from industrial land (Ruiz et al., 2012) to the land for the generation of renewable energies (Beriro et al., 2022; Ferrari et al., 2022; Rylatt et al., 2001). Digital tools are often used to facilitate discussion with stakeholders and visualise challenges for urban regeneration (Billger et al., 2017) allowing better informed decisions to be made. More recently in the urban development sector technologies have been developed to support the creation of so called Smart Cities (Stratigea et al., 2015) where the infrastructure of cities actively collects data to manage services and resources and support city planning (European Commission, 2022). These digital tools support Smart City development through mapping existing land-use and assets, real-time data collection, modelling the urban environment, improving communicating between stakeholders, and identifying public priorities for smart city development policies (Stratigea et al., 2015). Similar, digital technologies have been developed to assess sustainable development options the aim of improving climate change resilience for urban areas (Balogun et al., 2020). Within the UK brownfield sector, digital tools are often used to support decision makers throughout the brownfield redevelopment process, this includes site selection and planning as well as site development activities (Fig. 1). These digital tools vary in complexity and application, for example, spreadsheets containing statistical models to assess contamination (CL:AIRE, 2020) and proprietary post-site investigation soil logging software, *HoleBASE™* (Bentley Systems, 2021a), or continuous monitoring ground gas monitoring systems (Schloemer et al., 2013). The use of *AutoCAD* software (or similar) for technical drawings or site plans is also commonplace across the brownfield redevelopment sector. Additionally, Geographical Information Systems (GIS) are utilised during several tasks that rely on geospatial data throughout the redevelopment process (Fig. 1), from early-stage decisions like site selection and appraisal (Nogués and Arroyo, 2016), to late-stage tasks such as site investigation design, and 3D modelling of contamination (Velimirovic et al., 2020). The use of digital tools has become so important that innovation and advances in digital technologies are often recognised by industry awards (Environment Analyst, 2021).

In the academic literature, over the past two decades, digital tools and decision support systems (DSSs) have been used developed to support brownfield decision-makers across the world (Hammond et al., 2021). Existing DSSs have been applied to many different brownfield applications throughout the development process, including, remediation technology selection, land-use planning and site-selection, contamination modelling, as well as numerous other specialist applications.

The incorporation of stakeholder preference, through well-designed stakeholder analysis and engagement, is crucial in digital tool development (Leonidou et al., 2020) particularly; requirements gathering, ideation, and development. Existing stakeholder engagement for brownfield digital tool development has typically consisted of consulting a small number of experts focussing on one aspect such as remediation technology selection or modelling groundwater contamination plumes (Hammond et al., 2021).

Recent review work in the academic literature has discussed the need for brownfield digital tools and DSSs should seek to become more holistic in their scope, conducting wide-ranging stakeholder research (Drenning et al., 2022; Hammond et al., 2021). Findings from existing research show that the scope of stakeholder engagement for digital tool

development should also be widened to assess a greater variety of issues and include input from a wider variety of stakeholders. Doing this would offer greater inclusivity of all views and the introduction of different perspectives for redevelopment options by highlighting the benefits and drawbacks, leading to improved decision making (Drenning et al., 2022; Hammond et al., 2021). Digital tool development projects that implement this stakeholder engagement approach have the potential to not only solve their specific problems but also to support communication across stakeholder groups and disciplines. By surveying stakeholders from outside of the project (i.e. large-scale stakeholder consultation), novel intelligence and unanticipated findings could be elucidated, benefiting both the individual project, but also more general brownfield applications.

This paper presents findings from a stakeholder consultation campaign involving UK brownfield and contaminated land professionals conducted in 2020 and 2021. The research was designed to ascertain the level of digitalisation within the UK brownfield sector, to highlight key brownfield redevelopment issues, and to identify opportunities for digital tool development to enhance brownfield decision making throughout the planning and redevelopment process.

2. Methodology

The method chosen to elicit the views of stakeholders in the brownfield development sector comprises five steps, and aligns with the Interaction Design Foundation's *Design Thinking* methodology (Interaction Design Foundation, 2022). The five steps for our stakeholder consultation are (1) stakeholder identification and mapping; (2) planning and preparation of information elicitation activities; (3) key stakeholder semi-structured interviews; (4) large-scale online questionnaire; and (5) analysis and interpretation of results.

2.1. Stakeholder identification

Stakeholder identification and mapping was undertaken through preliminary expert discussion in the research team and reading of literature concerning stakeholder engagement in the brownfield sector (Bartke et al., 2016; Bartke and Schwarze, 2015; Huysegoms et al., 2019; Rizzo et al., 2015; Song et al., 2018). These stakeholder categories were then grouped using a stakeholder map with regards to their involvement in the redevelopment of brownfield sites. (Fig. 2). Three stakeholder categories were established as follows: (1) Core stakeholders, roles directly involved with the day-to-day planning, redevelopment, and management of brownfield sites, (2) Involved stakeholders, organisations that support and influence the brownfield redevelopment process by supporting core stakeholders through research, financial and legal advice, regulatory support, or developing new methods and technologies, and (3) Informed stakeholders, parties not directly involved in the day-to-day redevelopment of brownfield sites. This information then allowed us to identify which stakeholders to interview, survey, and which stakeholders are less involved with the brownfield redevelopment process.

2.2. Planning and preparation

Prior to contacting the stakeholders identified in Step 1, scoping and design of an online questionnaire was conducted to review and identify common brownfield and data issues. This involved researching existing

and emerging issues for brownfield redevelopment, as well as the adoption and application of digital tools within the sector. Consultation of the literature and other publications, trade magazines, government, and public sector guidance was undertaken, culminating in the publication of a critical review (Hammond et al., 2021). These findings were then discussed with project experts to ensure the survey was technically sound and relevant. Following this scoping exercise, commonly used methods (Morgan, 1996; Rizzo et al., 2015) were selected to elicit information including semi-structured informal interviews (face-to-face, virtual, and group sessions) and the use of online questionnaires. At this stage, the online questionnaire structure and questions were drafted and finalised following an analysis of insights from key stakeholder interviews.

2.3. Key stakeholder interviews

Interviews with experts from the key technical stakeholder categories were conducted to validate understanding and assumptions from step two (planning and preparation) and to aid in the design of the large-scale online stakeholder questionnaire. A semi-structured interview method was used (Longhurst, 2016). Interviews were conducted, initially in-person, and then virtually after COVID-19 restrictions were imposed in the UK. Five experts from the areas of consultancy, remediation, research, and data services were contacted. These stakeholder types were selected as they are exposed to a diversity of problems and roles across the sector and therefore, they are knowledgeable about a range of issues. The semi-structured interviews implemented a standardised set of questions to act as a guide for discussion with stakeholders and experts. These questions (Supplementary Materials) consisted of two profiling questions, four questions assessing their current levels of digitalisation, and three questions seeking to identify key brownfield issues from their perspective. They were used to ensure replicability between the individual interviews, and to allow for direct comparison between stakeholder groups. This approach allowed for a better understanding of the key issues and the creation of stakeholder personas (Table S1), in turn allowing the questionnaire to be designed in the best possible way.

2.4. Online questionnaire

The online questionnaire was designed to investigate issues identified during key stakeholder interviews and also to be aimed at typical brownfield stakeholders (see Table 1). The questions were based on five types including: (1) open, (2) closed, and (3) ranking questions, along with (4) Likert scale questions and (5) free text boxes. Open question styles were used to allow respondents to give unrestrained free responses. By contrast, on certain specific issues (such as common digital tools used for decision making) closed questions and ranking questions were used to ensure consistent answering styles, to allow direct and easy quantification and analysis of results with a comparison between stakeholder groups. Similarly, a Likert scale approach was used to record stakeholder attitudes, and to directly compare against other stakeholders.

The questionnaire contained 29 questions, partitioned into three main sections (Supplementary Materials). The first section contained six questions about the respondent, including contact details, type of stakeholder, typical projects, seniority, and experience. The second section contained ten questions about digitalisation and digital tools the stakeholders and their organisation typically use to make decisions. The

final section included six questions concerning key brownfield redevelopment issues.

The questionnaire was developed and hosted using the Qualtrics™ Online Survey Software (Qualtrics, 2021). The questionnaire was distributed through a variety of channels, including targeted distribution to fifty experts (Consultants = 19, Regulators = 3, Remediation Contractors = 10, National Government = 5, Local Authority Planning = 10, Scientific research community = 3) in the UK brownfield sector, industry mailing list, Contaminated Land Management Discussion list (~1400 members) (JISCMail, 2022), contaminated land/brownfield professional bodies, including CL:AIRE, 2022 and SoBRA (Society of Brownfield Risk Assessment) (SoBRA, 2022) (~>3000 members), and distribution through social media channels including LinkedIn® and Twitter. The questionnaire was run over nine weeks from 20th July 2020, until 21st September 2020.

2.5. Analysis and interpretation

2.5.1. Interviews

Qualitative data resulting from interviews was transcribed and analysed manually to identify the key themes and intelligence, to create stakeholder personas (Supplementary Materials, Table S1), and to support the design of the online questionnaire.

2.5.2. Questionnaires

Quantitative and qualitative data resulting from the online questionnaire were collected automatically using the Qualtrics™ software. The Qualtrics™ software platform was used to generate automatic graphical, tabulated and statistical summaries of the quantitative response, and to group responses based on other question responses (i.e. stakeholder type). Prior to analysis, data cleaning of the textual responses was carried out. This involved correcting spelling and grammatical errors in responses to aid automatic analysis of responses. Qualitative responses from the questionnaire were analysed with a combination of manual textual analysis and automatic qualitative analysis using the NVivo™ software (QSR, 2021). Keywords and themes were identified coded and quantified using a combination of automatic and manual coding. The automatic coding is built into NVivo™ and operates by analysing the uploaded text and identifying and quantifying common keywords, sentiments, and themes. By contrast, manual coding achieves the same, but the user identifies the instances. Word-cloud graphics were also generated in NVivo™ and Qualtrics™ software for use in this study. These are natively within the software with the only intervention being to remove irrelevant common English words (e.g. the, and & etc.) Insights generated from the quantitative and qualitative analyses were then used to map and correlate responses among the key stakeholders to elicit their views on the opportunities that digitalisation offers to the brownfield redevelopment sector.

3. Results and discussion

3.1. Stakeholder identification

The generation of stakeholder types was achieved through means of literature review and discussion within the research team. This resulted in the identification of 17 different stakeholder categories (Table 1). As outlined in section 2.1, the stakeholder types were grouped into three categories: Core Stakeholders, Involved Stakeholders and, Informed Stakeholders (Fig. 2).

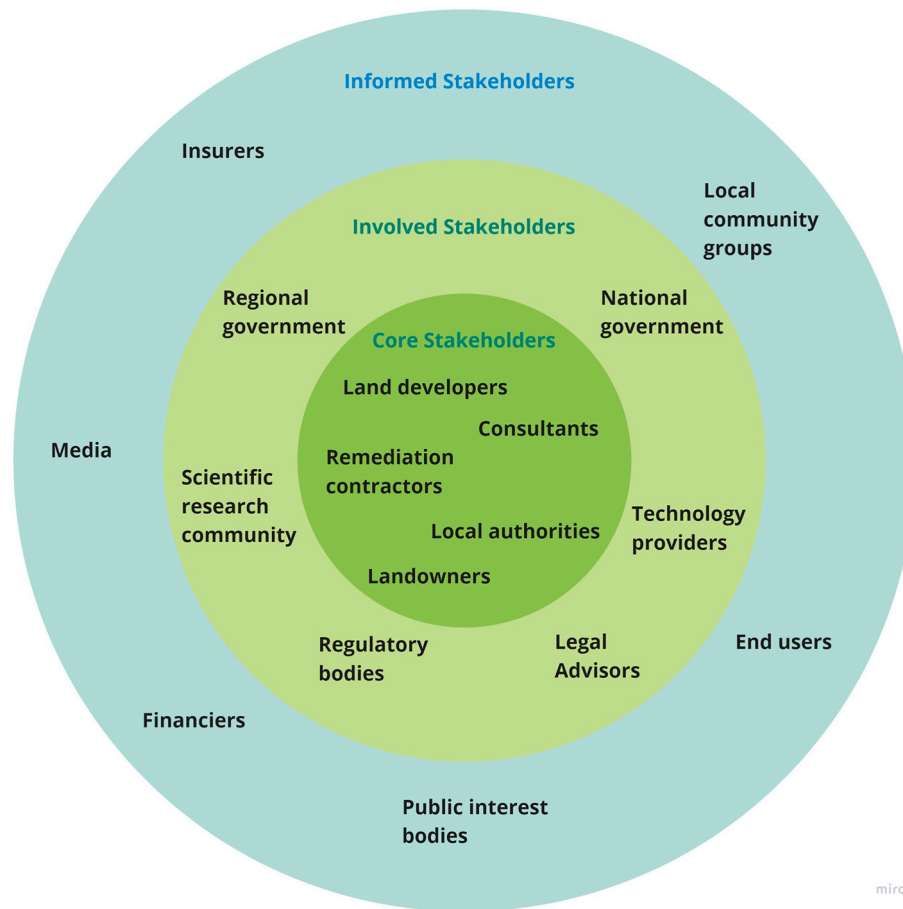


Fig. 2. Stakeholder groups identified and mapped based on their involvement in the brownfield redevelopment process.

Table 1
Stakeholder categories.

Stakeholder Category	Profile
1 National government	Ministerial and non-ministerial departments responsible for land redevelopment.
2 Regional government	Regional and local authorities concerned with planning, spatial planning and management of land resources.
3 Local government	
4 Regulatory bodies	Protection agencies concerned with the environment, soil, water, waste, Health & Safety.
5 Public interest bodies	Non-Governmental Organisations (NGOs), campaign groups, Chartered Institutions.
6 Landowners	Land/Site owners, or persons responsible for contaminated sites, liable parties.
7 Local community groups	Residents and/or local businesses organised into groups on local social issues.
8 Developers	Agents purchasing sites/land to improve and develop it for re-sale to the public or other organisations, including housebuilders, commercial and industrial developers.
9 Consultants	Environmental engineers, ecologists, planners, designers, civil engineers, geotechnical engineers etc.
10 Technology providers	Organisations seeking to develop and sell environmental remediation technology and solutions.
11 Contractors	Organisations specialising in conducting works such as remediation, construction, groundworks, utilities.
12 Financiers	Private or public organisations, investing or lending money for the development of sites/projects. Such organisations may also advise other organisations on financial matters.
13 Insurers	Organisations that support risk transfer, evaluating ongoing risk or carrying residual risk for developments.
14 Scientific research community	Researchers, academics and students conducting research and development advancing the understanding of brownfield issues.
15 Media	Media reporting on developments and issues of public interest. Media organisations may be used to promote the success of a redevelopment project.
16 End users	The final end-users of a development – seen as a receptor in the SPR linkage model.
17 Others	Any other stakeholder relevant to brownfield redevelopment.

3.2. Initial stakeholder interviews

The following subsections detail findings from interviews with the five key stakeholders (section 2.3), separated into the two themes of our investigation.

Digital Tools: The five interviews conducted in provided valuable insights into current stakeholder digitalisation across the brownfield sector. Results indicate that many businesses and organisations across the sector are currently undergoing a ‘digital transformation’ (a transition from paper-based or disparate digital methods to integrative digital ways of working). Consultants state that this is especially true for how they carry out fieldwork with the increased use of GIS and Bluetooth systems. These systems are allowing them to send and share data more efficiently across systems and software platforms, in the field and when they are processing data from fieldwork. These include AutoCAD™ software to produce technical drawings and models and the increased use of post-site investigation software (such as HoleBASE™ and GINT™ (Bentley Systems, 2021a,b).

Despite this growing trend for the implementation of new digital workflows, all interviewees identified several challenges such as different individuals’ project management styles (i.e. attitudes to risk and time allowances for key processes) often resulting in inconsistencies in the quality and completeness of the data. For example, less risk-averse clients may choose a cheaper and quicker site investigation meaning that the resolution of data around ground conditions may be poor. Similarly, data from previous site investigations are often disparate, being held in a non-structured manner within individual company databases & networks. This means that data and information are often either not used or overlooked entirely.

The interviewees all confirmed that their organisations were receptive to new developments and digital techniques and would be keen to adopt new digital tools where this would benefit their operations. Similarly, interviewees, particularly consultants, noted the sector should be able to evolve and embrace new technologies to “future-proof” the sector, allowing for “stakeholders within the sector to provide innovative solutions and services to their clients and the public”.

Key Brownfield Issues: Generally, interviewees shared the same foremost issue, the cost of redeveloping brownfield sites. Their experiences highlighted the biggest cause of failure of brownfield projects as the failure of developers and supporting organisations (e.g. contractors, consultants, local government) to dependably estimate costs throughout site redevelopment programmes. A shared concern was that “abnormal

and unexpected ground conditions can often lead to cost increases and delayed completion dates” – Remediation Contractor, something also reported in the literature (Ameller et al., 2020; Connaughton and Mbugua, 2008; Male, 2008). However, the consultants and remediation contractor pointed out that sometimes, ground conditions are better than initially thought, and projects can finish earlier than planned, resulting in lowered costs.

Another aspect of importance noted was that the lack of understanding of the redevelopment process can lead to problems, highlighting that having a large group of project stakeholders can lead to a conflict of preferences and attitudes to risk and development opportunities. One of the consultants noted that “some developers don’t place enough importance on transport planning and as a result, a development has poor links and access to sites, and this can often make the development unviable”.

A commonly expressed view by consultants was that brownfield sites are typically developed for housing or strategic logistical developments. With logistic/commercial developments there is often a short planning program with a quick turnaround on high-value purchases. As a result, there is a “need to be able to have accurate and early estimates of expected costs” – Consultant, for redeveloping such brownfield sites.

3.3. Online stakeholder questionnaire

The online questionnaire was distributed to an estimated 4000 potential participants and recorded 150 responses. However, if partial responses are removed the total number of full responses dropped to 98. The analysis did not segregate partial completion responses as they provide useful information. Questionnaire respondents originated from a wide range of stakeholder groups (Fig. 3) and represent a range of seniorities and experience levels (Supplementary Materials, Table S2). As shown by Fig. 3, the majority of questionnaire respondents were consultants, when asked to specify, all of them stated that they are a geoenvironmental or geotechnical consultant. Local Authorities planning and development roles make up the second-largest respondent type, followed by similar numbers of Regulators, National Government, Developers and Landowners. The majority of stakeholders who responded to the questionnaire were at a senior level or above (62%) with more than 15 years’ experience (48%) and the majority being qualified to master’s degree or doctorate level (71%).

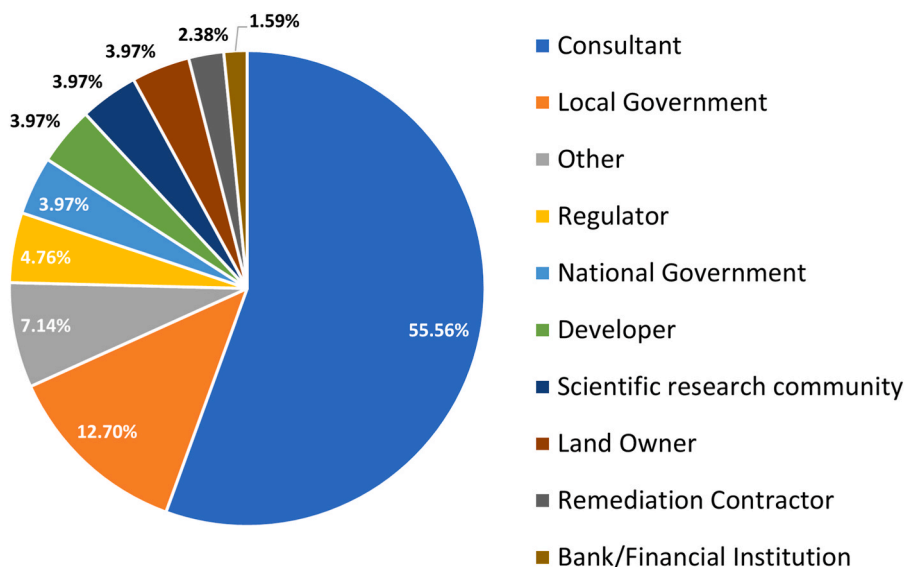


Fig. 3. Questionnaire response by stakeholder type.

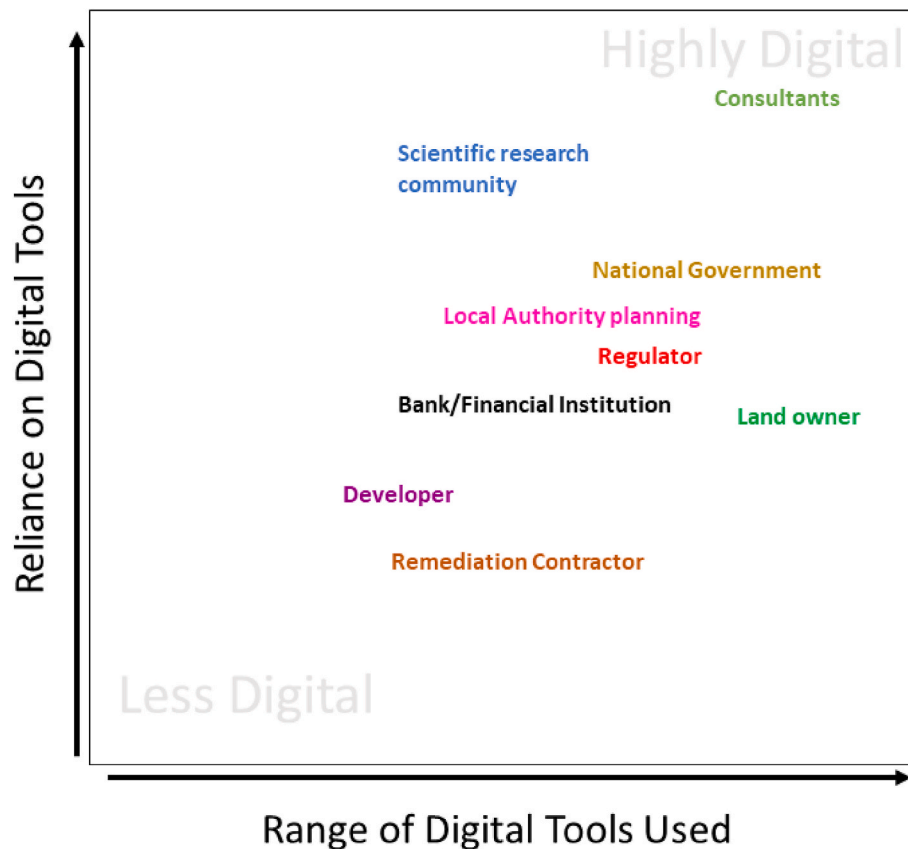


Fig. 4. Use and reliance on digital tools across stakeholder types.

3.3.1. Digitalisation

The majority of the respondents (81%) self-assessed as having a ‘moderately’ or ‘very digitally enabled’ workflow (where they use a variety of digital tools as part of their daily tasks), with a smaller number (8%) self-assessing as extremely digital. The following subsections present digitalisation question responses grouped into key stakeholder types allowing us to evaluate stakeholder attitudes across the sector.

Fig. 4 is a plot of the digital capabilities of the stakeholder who responded to the questionnaire. Observations from data produced by the questionnaire suggest stakeholders fall into one of four types; (1) Highly Digital – The use of multiple digital tools frequently throughout their decision-making process, (2) Moderately Digital – The use of multiple digital tools less frequently throughout their decision-making process, (3) Somewhat Digital – the use of a smaller range of digital tools, but a high reliance on these tools in their decision-making process, (4) Less digital – The use of a small range of digital, infrequently through their decision-making process.

From data gathered in the online questionnaire, we observed that there is a trend for stakeholders that use lots of tools to have a greater dependency on them for decision making when compared to those that use fewer digital tools (Fig. 4).

Insights from this plot of digital capabilities (Fig. 4) show a few potential ways in which new digital tool development may help different stakeholders. For example, stakeholders such as Developers and Remediation Contractors, digital needs may be in upskilling in digital workflows and adoption of already present digital tools. More digitally capable stakeholders such as Consultants may be better aided with digital tools that fit into their already established digital workflow, or by novel digital tools that do something different than existing tools and systems.

3.3.1.1. Remediation contractors. Two of the three remediation

contractors reported that their organisations were ‘moderately digital’, with one reporting ‘not at all digital’, basing their decisions on the results of digital tools used only infrequently. This may indicate that remediation contractors are not as digitally enabled as other stakeholders. However, remediation contractors often work for larger civil engineering contractors that frequently utilise digital systems, such as Building Information Modelling (BIM) systems. This perhaps indicates that the wider project team associated with remediation may be more digitally enabled. Remediation contractors mostly use *Excel* and *AutoCAD*™ software mainly to produce drawings and models to support remediation design, execution, and validation. A wide variety of data is used by remediation contractors, but mostly comprises site investigation data, including soil and rock logs, chemical test results and geotechnical test results. Environmental spatial data and non-spatial data are often used by remediation contractors, and environmental data reports are often purchased or inherited from previous Site Investigation (SI)/Ground Investigation (GI). Most remediation contractors agree that their current systems are of high enough quality to carry out their tasks. This may indicate that future digital tools may be of limited help for remediation contractors given their current state of digitalisation.

3.3.1.2. Land developers. Land developer respondents self-assessed as being ‘moderately digital’, basing their decisions on digital tools most of the time. Their use of digital tools is generally more dominant during strategic and master planning stages, where reliance on outputs from digital tools is greatest. Their outputs are then refined as the development process progresses. Numerous kinds of data are used, particularly land value data and other infrastructure datasets (e.g. highways, energy), not always used by another brownfield stakeholder who responded to the questionnaire. Environmental datasets are also used to a lesser extent, as environmental constraints and ground conditions are often considered as part of work carried out by third-party consultants or

ground investigation specialists which are then used to make professional recommendations back to the developers. One respondent indicated that increased use of GIS is expected in the future with the use of “more GIS-based data” as developers seek to be more digitalised, adopting and integrating digital tools throughout the site development process.

3.3.1.3. Local Authority Planning. Local Authority (LA) (Local Government) planners self-assessed as either moderately or very digital, which is aligned with the efforts seen in recent years to modernise and digitise the planning process in England and other parts of the UK (MHCLG, 2018). Despite this, they only base decisions on digital tool outputs in 50% of cases. LA planners mostly use GIS and spreadsheets during all stages before planning consent (Fig. 1) is granted with some use of WebGIS. In the future, planners are seeking to incorporate a wider variety of datasets into their decision making. Currently, they utilise environmental, infrastructure and planning datasets. Future datasets of interest indicated by respondents might include “deprivation indices”, “food growing availability”, “greenspace”, “heritage”, and “active travel datasets”. One respondent also commented that they: “would like to see if we can access more public health data that could be tied into prioritising work”. This comment may be a reaction to COVID-19, but it does demonstrate that planners and local authorities are looking towards using different and not previously considered datasets to support their decision-making. Generating meaningful results from these datasets may be improved with the development of new digital tools.

3.3.1.4. Consultants. Consultants were the most digitalised of the stakeholders, with half of the respondents self-assessing as being extremely digital. There is some disparity in the use of digital tools for decision making, with 33% of consultants using digital tools sometimes, 33% half the time and 33% most of the time. Common digital tools used by consultants include spreadsheets, GIS, AutoCAD™ software, digital fieldwork equipment and 3D modelling software. Additionally, the majority of consultants also commented that HoleBase™ is used, specifically utilising the .ags file format. The .ags is a text file format developed by the Association of Geotechnical and Geoenvironmental Specialists (AGS) for the transfer of site investigation data (including borehole positions, soil and rock descriptions, sample depths etc.) (AGS, 2022). Consultants use the largest variety of digital tools of any stakeholder group, and throughout the entire development process, unlike other stakeholder groups. This variety and reliance on digital tools perhaps reflect the range of assessments and services the consultants provide. This could also be because to perform their role they require the use of a broad range of different software tools or that using this range of tools gives them a competitive advantage or helps with communication of findings to their clients. The digital tools and software used during desk studies differ from the kind of tools used during post-site investigation/analysis phases (Fig. 1). During post-site investigation, specialist software and tools are used such as subsurface 3D modelling or spreadsheet models to statistically analyse contamination concentrations in soil, whereas during desk study, multipurpose digital tools are used such as AutoCAD™ and GIS.

Consultants utilise the widest variety of spatial data (e.g. geo-environmental, geological, spatial planning, site-investigation locations) in their day-to-day operations, drawing upon a wide range of environmental data types throughout the decision-making process. Consultants also commented that having “better digital tools would enable more efficient processing [of data]” and a “clearer presentation [of data]”, and that existing systems can compartmentalise their analysis, which is time-consuming. Feedback from consultants suggests that in the future they would look to further “increase the use of GIS” and spatial data for evaluating the ground conditions of sites and creating spatial outputs for their clients.

Table 2

A ranking of key brownfield redevelopment issues as determined by stakeholders who responded to the questionnaire..

Rank	Key Issue	Mean Score
1	Remediation costs	4.06
2	Unforeseen ground conditions	4.05
3	Presence of hazardous substances e.g. Asbestos, chemical contamination etc.	3.97
4	Awareness of the brownfield redevelopment process	3.54
5	Land prices	3.54
6	Environmental Constraints	3.48
7	Unit sale prices	3.42
8	Geography and infrastructure (e.g. road links, waste management proximity etc)	3.41
9	Availability of scientific data – below ground	3.40
10	Improper development end-use	3.28

3.3.1.5. Regulatory bodies. Regulators (including the Environment Agencies for England, Scotland, and Wales) self-assessed as being moderately (50%), very (33%), or extremely digital (17%). They use a variety of digital tools to help them make their decisions, including spreadsheets, data visualisation tools, GIS and WebGIS. Regulator respondents also stated that they rely on digital tools for their decision making at least half of the time (17%), most of the time (67%), or always (17%). Regulators utilise different digital tools throughout their operations, for example using GIS tools when deciding whether to place a contaminated land condition on a development or when conducting an initial risk screening and for the development of conceptual site models. Spreadsheets are often used for numerical modelling for risk assessment of chemical contamination. A wide range of digital tools are used for risk assessment, where they offer non-statutory advice to LPAs, land developers, professional advisors, and strategic planners. Regulators also make use of a range of environmental and non-scientific data, including many of the datasets being owned and curated by regulators themselves (i.e. national flood risk datasets). The respondents state that they somewhat agree their existing systems are suitable for their needs, but in the future want improve their GIS and mapping capabilities.

3.3.1.6. Scientific research community. Respondents from the scientific research community self-assess as being either very digital (50%), extremely digital (25%) or, moderately digital (25%), often using digital tools to make decisions with (75% always or more). They utilise a variety of digital tools in their decision making, mainly spreadsheets for the analysis of experimental data, and GIS/WebGIS tools for spatial visualisation of datasets. Scientific researchers also make use of a wider variety of software programming languages, including *Python*, *R*, and *MATLAB* for developing models or performing data transformations. Generally, the work of the scientific research community takes place outside of the mainstream brownfield site redevelopment process, but when involved, the scientific research community operates during detailed risk assessment, after intrusive site investigation has taken place. Scientific researchers were reported to make use of a smaller variety of data, mainly chemical and geotechnical testing results.

3.3.2. Barriers for brownfield redevelopment

One of the questions within the questionnaire was to score (1–5) the key issues/barriers that hamper or delay brownfield redevelopment (Table 2), with 1 being little to no impact and 5 being a major impact.

Respondents to the questionnaire collectively ranked remediation costs as the principal issue of concern. Furthermore, one question within the questionnaire was designed to determine explicitly if remediation and ground engineering costs have the biggest impact on a project. Responses to this show that most respondents “Agree” or “Somewhat agree” with the statement. Textual responses also reveal that location is also a major determinate on the economic viability of the site, with stakeholders from all groups mentioning location.

3.4. Challenges for brownfield digital tools

Results from the questionnaire indicate that there is still a large disparity between stakeholders. Consultancies, National Government, and the Scientific Research Community are the most digitalised brownfield stakeholder groups (Fig. 4). In contrast, remediation contractors and developers are the least digitally enabled. Not all stakeholders require digital tools to conduct their day to day operations, however, the addition of well-designed digital tools are seen to add value and support decision-making across the brownfield sector (Bartke and Schwarze, 2015). Uptake of new technologies by large organisations may lead to a trickle-down effect, where once new digital tools are used by early adopters, other organisations will follow.

Many different digital tools and data sources are often used for stakeholders to make decisions. Opportunities for future digital tools may include unifying or integrating data of different types into a unified platform or workflow, thus overcoming the disadvantages of using many different pieces of software to make decisions (Bartke and Schwarze, 2015). Other considerations for future digital developments include: (1) the need for a good degree of interoperability with the range of tools currently used (2) the possibility that future developments in the brownfield digital space may be constrained by the varied functionality of existing digital tools.

Stakeholder comments such as “Current digital systems and data handling are not good enough to fully characterise sites”- Consultant, or “Data management and visualisation could be improved in the sector” – Consultant, were common throughout the questionnaire responses. This indicates a key opportunity for future digital tools and data handling systems to aid decision-makers in manipulating and visualising existing data that is currently unable to be fully exploited.

Across the stakeholder groups, responses indicate that digital tools are often used throughout the brownfield redevelopment process, for specialised tasks. However, the dependency on digital tools for decision making is greatest during the early stage of redevelopment, where sites are being evaluated and investigated. This suggests that digital tools applied in the early stages of decision making may be most useful, fitting into well-established workflows.

Textual responses to the question on future digitalisation plans indicate that there is an expected increased uptake of the use of spatial data (environmental data, spatial planning data, population data, public health data etc) and GIS software across the sector, where not already used, and increased integration of these technologies where not already commonplace. Because of this, both current and future digital tools, data and decision support systems will need to become interoperable with spatial software and workflows (i.e. web-based spatial analysis and data management). As indicated by the stakeholder comments/feedback

throughout Section 3 of the online questionnaire, the adoption of digital tools and data systems will be crucial for improving decision making across the sector. We also identify that the improvement of digital technologies as communication tools has the potential to allow technical stakeholders and expert to engage with peripherally involved stakeholders (Fig. 2) allowing them to understand and contribute to the redevelopment process in a way not previously allowed. However, future developments are not without their challenges (Gebhart et al., 2016). As shown by our questionnaire, stakeholders’ interest in the adoption of new technologies is strong (75%). Strong user interest in the testing of new tools should lead to the improvement of tools by developers as they become increasingly tailored to the stakeholder’s needs. This continuous improvement process of stakeholder involvement, user testing and product refinement should lead to an increased embedding of digital tools into the workflows of many brownfield stakeholders, in turn resulting in better decision making.

Stakeholder issues around quality of data visualisation provide a good mandate for new digital tools, where a large variety of data (environmental, social etc) can be visualised together, as well as adding value through generated outputs, overcoming existing issues of digital systems identified by stakeholders.

Uncertainty around unforeseen ground conditions constitutes the second most frequently selected issue. Textual analysis of the questionnaire provides evidence that the lack of understanding of ground conditions and the risk associated with ground contamination and instability leads to problems with project/site development. For example, one consultant states that “clients not appreciating the impact of ground risk” have a big impact on project overrun and overspending. However, there are several key differences between stakeholders. Generally, ground conditions are seen as representing a considerable barrier by technical experts (i.e. consultants, remediation contractors etc). In contrast, developers and planners do not consider ground conditions as a significant barrier, indicating issues around risk understanding or risk communication. The various stakeholder groups identify different issues as problematic for brownfield redevelopment depending on their area of specialism. Table 3 shows the variability between key stakeholder groups when they were asked to rank key brownfield issues within the questionnaire. The key brownfield issues shown in Table 3 are the top ten key issues identified shown in Table 2.

Analysis of textual responses indicates that Developers and Contractors may see economic and time constraints as being the most important, whereas regulators and local governments see risk reduction and regulatory compliance as paramount. It is this difference in perspective that may potentially lead to a lack of understanding of key issues between stakeholders and specialists which in turn can lead to further problems with project management and communication.

Table 3
Variability of key brownfield issues between key stakeholder groups.

Stakeholder Group	Key Brownfield Issue (mean score)									
	Availability of scientific data – below ground	Awareness of the brownfield redevelopment process	Environmental Constraints	Geography and infrastructure	Improper development end-use	Land prices	Presence of hazardous substances	Remediation costs	Unforeseen ground conditions	Unit sale prices
Consultant	3.36	3.37	3.45	3.52	3.2	3.39	4.04	4.11	4.23	3.24
Developer	3.25	3.5	3	3	3.33	4.75	3.25	4.5	3.5	4.33
Landowner	3.25	3.5	3.25	3.25	3.25	4.5	3.75	4.25	4.25	4
Local Government	2.8	4	4.25	4.17	3.33	3.29	3.71	3.71	3.57	3.17
National Government	3.33	3.33	2	4.67	4.33	4.33	3.33	4.33	3	4.33
Regulator	3.33	3.83	3.75	2.67	2.83	2.67	4	4.33	4	2.67
Remediation Contractor	4	4.67	3	3.33	3.67	2.33	5	4.33	4.33	3.67
Scientific research community	3.67	3.67	3	2.67	3.5	3.67	4	3.33	4.33	4

3.5. Opportunities across the brownfield sector

Across the urban planning and redevelopment sector, many technologies and digital tools are beginning to be adopted and used for a variety of tasks. For example, the use of unmanned aerial vehicles (UAVs) and drones is now commonplace (Geoterra, 2022; Routescene, 2022; South West Surveys, 2022). These UAVs and drones can also carry several sensors such as LiDAR for the creation of high-resolution digital elevation models of sites and buildings. To process this raw data, many organisations utilise high-processing power computers and 3D modelling software to produce meaningful outputs for their clients. Once generated, 3D models and scans can be viewed by users in virtual reality to or view 'in-situ' by using augmented reality technologies (Oke and Arowoija, 2021; Safikhani et al., 2022) making it easy for stakeholder to relate what the data is showing to the real world. Similarly, the creation of so-called 'digital twins' for urban areas is now also underway. Digital twins are digital representations of physical things. The Centre for Digital Built Britain (CDBB) is working to create the National Digital Twin programme (NDTp) (CDBB, 2022) which is seeking to create a digital twin for the built environment across the UK. This digital twin will include buildings, infrastructure, and eventually subsurface assets (Cabinet Office and Geospatial Commission, 2021). The NDTp will improve how infrastructure is built, managed, and operated to support planning and development for urban areas. The UK government recently published the UK's Digital Strategy (UK Government, 2022), building on the 'levelling-up' agenda. This policy paper further demonstrates the UK Governments drive towards digitalisation and adoption of new digital technologies across different sectors (UK Government, 2022).

Across the land development sector in the UK, there is a recognised emphasis being placed on digitalisation for the planning and redevelopment process, as well as access and management of data and geospatial data. For example; the UK government 2020 White Paper on planning for the future, pushing to increase the digital aspects of the planning system in the UK (MHCLG, 2020), the Geospatial Commission's report on finding geospatial data (Cabinet Office and Geospatial Commission, 2020), as well the publication and promotion of geospatial data standards (Ordnance Survey, 2022) in line with long-standing 'FAIR' principles (GO Fair, 2022) and international standards for geospatial data (ISO, 2020).

These digital initiatives seen in the UK planning and land development sector are also seen in other countries across the world. It is recognised by the European Union Joint Research Centre, that digital technologies will be pivotal in delivering a green and more sustainable Europe in the coming years (EU, 2022) and upskilling digital capabilities across sectors will ensure a sustainable future for people, the economy and society within Europe (European Commission, 2020). Likewise, the importance of digital tools to support environmental management decision making is also recognised by the US EPA which in recent years has developed many digital tools and data platforms, aligning with the US Foundations for Evidence-based Policymaking Act of 2018 (US Congress, 2018). The development of data-driven tools has been and will continue to be a response to governments and policy but also a reaction to industry requirements allowing organisations to provide a better, high-quality service to their customers, in both the private and public sectors.

Our findings suggest that one area for future digital tools could be in the identification and understanding of problematic ground conditions. This would not only allow for stakeholders to plan for these unforeseen ground conditions, but also communicating the risk to other stakeholders. For example, certain stakeholders or other interested parties may not fully understand the extent or nature of a contamination problem. By using modern digital visualisation tools, a consultant or planner may be able to communicate the problem and potential impacts to the development and plan. The foundation for tools of this nature are already present within the academic literature (Bartke et al., 2016; Hammond et al., 2021; Huysegoms and Cappuyens, 2017; Morio et al.,

2013). One regulator who responded to the questionnaire states that "Lack of communication between developers, planning teams and contaminated land consultants" represents the biggest cause of project overrun and overspending. By manipulating existing data and workflows, through new data visualisation and modelling, digital tools and DSSs may help stakeholders (including informed stakeholder (Fig. 2)), to better understand and communicate options and scenarios during project/development planning. Across all stakeholder types, development and risk mitigation costs, and the understanding of these costs, were by far the most important factor in the success or failure of a project. New digital tools and data systems have the potential to greatly improve how these risks/costs are quantified, presented, and understood. For example, as outlined by Hammond et al. (2021), improved user interfaces/user experience, the use of WebGIS, and the adoption of innovative geospatial and machine learning techniques. If these tools and data systems utilise the abundance of open environmental and geoscientific spatial datasets, the potential to model and visualise important issues is huge.

Insights from stakeholder engagement often lead to the establishment of guidance and frameworks for future DSS research, namely the international research by Bartke et al. (2016), Moya et al. (2019), and Pizzol et al. (2016). However, these frameworks and guidance are often created for an individual tool or system development. Here we present seven core principles for all future digital brownfield tools. These have been derived from specific insights produced from this stakeholder consultation study. Future brownfield digital tools should be: (1) Stakeholder driven – understanding and incorporating stakeholder preference remains key to tool development; (2) Problem centred – digital solutions should be created to respond to direct end-user need; (3) Visual – to engage a wide variety of stakeholders outputs from digital tools should utilise modern visualisation and graphical capabilities; (4) Intuitive – for ease of use tools should include intuitive functions and user experience (5) Interactive – enhance engagement from the end-user through interactivity and user participation; (6) Interoperable – there already exists numerous helpful digital tools, future developments should seek to align with or enhance these; (7) Geospatial data-driven – more and more decisions are being supported through with geospatial evidence and the uptake of geospatial methods is expected to continue to increase across the sector.

4. Conclusions

This paper has presented key insights from a stakeholder consultation on the potential that future development of digital tools and data systems will have on the brownfield sector. Our findings show that different stakeholder groups within the UK brownfield sector are at various stages of digitalisation. Digital tools and the uptake of new technologies have a great impact on how brownfield professionals currently work and will work in the future. Recent policy and guidance, as well as developments in the private and research sectors are driving the creation and adoption of new digital tools in the UK, Europe, and across the world. As the development and uptake of new technologies continues, future policies and practices, will be shaped to reflect these role digital technologies play in supporting decision makers. There are three key areas of brownfield redevelopment identified by this study where digital tools will have the biggest impact: (1) Supporting discussion around land-use planning, (2) Understanding of ground conditions and communication of the associated risk, and (3) Demystifying and quantifying economic factors related to developing brownfield land. Well-designed digital tools have the potential to revolutionise how the brownfield sector understands and communicate key issues leading to better decision making and more sustainable brownfield redevelopment.

Author contributions

E. Hammond: Conceptualization, Methodology, Analysis,

Investigation, Writing – original draft, Visualisation, Data curation. **D. Beriro, F. Coulon, S. Hallett**: Project administration, Conceptualization, Validation, Analysis, Resources, Writing-Review and Editing, Supervision, Funding acquisition. **R. Thomas, D. Hardy**: Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary data

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