DARE

Trusted Research Environment users

Evidence supporting a TRE usability principle

DARE UK

Trusted Research Environment users

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UKRI UK Research and Innovation

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Executive Summary

For Trusted Research Environments (TREs) to be safe, secure, and productive, they must also be usable. A TRE that is usable provides a productive and accessible analysis environment for research. Ensuring TREs are usable is a core concern of the Standardised Architecture for Trusted Research Environments (SATRE) specification, a reference TRE architecture and accompanying implementation created using a community-driven approach. This report contributes to that project in two ways. First, we provide a rich set of recommendations that builders and operators of TREs can follow to improve the usability of their TREs. These recommendations form the basis of a TRE *usability principle* which is incorporated into SATRE's specification architecture version 1.0. Second, we outline the methods and analytic perspectives we have used to understand users' needs and we recommend a series of future research ideas now required to advance this work.

The report's central contribution is to show that usability is both a technical property of TREs (that can be standardised and implemented at scale), and a sociotechnical characteristic that emerges in specific contexts of use and is influenced by users' needs, existing knowledge, skills, and prior experiences. This has important implications for future design and evaluation work that aims to improve TRE usability. Most significantly, it indicates that compliance with standard architecture should be complemented with contextual guidance, informed by knowledge about a diversity of local TRE users. In documenting our engagements with users – through group discussions, observations, and formal user testing sessions, we recommend ways in which this knowledge can be produced.

The report differentiates four user types common across different organisational and regulatory settings such as universities, healthcare, and industry. These are analyst-researchers, TRE operators, data research managers (who typically line-manage teams of analysts), and information governance users charged with compliance responsibilities. We use these user types to structure recommendations.

Our intention is that this report helps people in charge of making decisions within and about TREs not only understand the needs of their users, but also balance those needs with commitments to robust and reproducible research and analysis, as well as information governance and compliance. This report is intended to inform plans of how and where to direct support for new or migrating TRE users. Specifically, whether trade-offs between safety, security and productivity might be best addressed through technical changes to TREs on the one hand, or through alternative means, such as training, the provision of ongoing support, interventions in organisational rules or practices or by other means entirely.

Finally, looking beyond the bounded scope of this pilot study, we point to several promising and urgent directions for future work that aims to better understand TRE users and to design TREs that are more useable.

Organisations and projects mentioned in this report

Trusted Research Environments (TREs) are designed to enable access to sensitive data only for authorised projects and researchers, whilst minimising risk of data release or exposure. Sometimes they are referred to as SREs (safe research environments), DSHs (data safe havens), SDEs (secure data environments) or similar terms. Influential reports from DARE UK and Health Data Research UK, together with the UK Government Goldacre review and 'Data Saves Lives' policy paper, have all highlighted the need for change in how sensitive data are handled, and are driving the development of TREs in the UK.

DARE UK (Data and Analytics Research Environments UK) is a programme funded by UK Research and Innovation (UKRI) to design and deliver coordinated and trustworthy national data research infrastructure to support cross-domain research for public good.

At the moment there are many teams building and running many different TREs – there's no clear picture of what a 'good' TRE is, and this siloed approach prevents collaborative, effective research taking place. As part of the **SATRE** project (Standardised Architecture for Trusted Research Environments), we're building an open reference specification for TREs, that can move everyone towards a common understanding and approach for TRE provision. SATRE is a collaborative research project between the University of Dundee, Ulster University, UCL, HDR UK, The Alan Turing Institute & Research Data Scotland, and funded by DARE UK. The SATRE project provides a Standard Architecture for TREs, incorporating knowledge and best practices from multiple institutions and sectors across the UK. It aims to standardise the different necessary capabilities of TREs, making it easier for users, operators, and developers to work with sensitive data, and making the operation of TREs more transparent to data owners, impacted parties and the public.

1.   Introduction and background to this report

1.1.   How users are understood across today's TRE development landscape

Trusted Research Environments (TREs) were created to meet the needs of data controllers in fulfilling obligations to data owners. TREs are designed to manage risk and create an overall trustworthy environment – to provide safe social and technical infrastructure that support sensitive data research. Users are critical stakeholders of TREs as highlighted in the *DARE UK Federated Architecture Blueprint* (DARE UK Blueprint).[1]

So who are TRE users and what do they do? The DARE UK Blueprint conceptualises a set of distinct roles that may exist across UK federated TREs. These roles include (i) data providers such as data controllers responsible for guarding access to data, including data about the public, and data custodians responsible for curating and maintaining data; (ii) Data consumers such as academic and commercial researchers looking to access sensitive data to address research questions or test new products or services through data analysis techniques; and (iii) what the DARE UK Blueprint calls 'connectors ', examples of which are information governance professionals, indexers and linkers of data and TRE operators who are responsible for running TREs under particular information governance regimes.

The details of these roles are useful for designing architecture and delegating responsibilities across networks. However, in order to understand how these roles play out in organisations and amongst workforces and research students, we need to know more about how these infrastructure roles are performed in often complex real-world settings, and by whom. Simply put, we need a better understanding of TRE users' needs and how to build and evaluate TREs against these needs.

Why is SATRE interested in knowing about TRE users?

The aim of the SATRE project is to build standardised TRE architecture for infrastructure that supports users doing safe and trustworthy data research. That work involves thinking about both the technical layer of TRE architecture as well as how and where this technical layer meets social issues of compliance and information governance. However, the sociotechnical borderland between technical (and therefore potentially standardisable) architecture on the one hand, and social and information governance (IG) issues (that we think are best left to decision makers in specific organisations) on the other, is complex, uncertain, and often ill-defined.

Inhabiting this borderland are users. Considerations of who users are, what they know and what they need informs not just *how* to design or standardise our TRE architecture, but also *what* to standardise. The critical issue is this: usability is not simply a feature of technology that can be standardised. It is also informed by users' skills,

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[1] The DARE UK Blueprint outlines prospective development pathways for the DARE UK federation of TREs. See DARE UK Delivery Team. (2023). *Federated Architecture Blueprint*. DARE UK (Data and Analytics Research Environments UK). https://dareuk.org.uk/our-work/federated-architecture-blueprint/

knowledge, prior experience, and expectations of what it is technology should do, and the tasks users need to complete in order to get their jobs done. A slow virtual machine may be understood by one user but cause intense frustrations in another.

This kind of usability problem is one that can be approached in multiple ways. This could be through strict technical enforcement, for instance refactoring the TRE to alter how it is provisioned to the user, or through interventions at the level of the organisation, for instance by providing support or training. In order to help us think through an architecture principle that would help guide these kinds of decisions, we have set about compiling contributions from TRE users in the real world. The principle is explained in Section 4.

In addition to informing thinking on our architecture principle, these contributions may also be useful in systematically thinking through a number of related issues. These include: scoping needs for training and hiring schemes; adapting data infrastructure to match existing and future user needs; building evaluation schemes for the SATRE architecture or compliance work that consider the context of research and users; planning the migration of TREs and their users, for instance when implementing the SATRE standardised architecture.

1.2.   The evidence base for this report

Work that contributes to this report was carried out between April and October 2023. Four sets of structured interactions with different kinds of TRE users across the UK TRE landscape were organised. Observations and unstructured conversations with data analysts took place during a week-long Data Study Group on-site at the Alan Turing Institute in London. Following that, two 90-minute dialogue sessions were convened online, where a diversity of TRE users discussed their experiences working with TREs and working with other TRE users. Participants were drawn from mailing lists of the SATRE project and researchers working within TREs, snowballing from there. In these sessions we wanted to understand the situations and contexts of use; what good looked like from the perspective of users; and issues, needs, barriers, and frustrations encountered in achieving that good.

The subject of users and usability were prominent at two *Collaboration Cafés* run by the SATRE project. Collaboration Cafés were regular one-hour online meetings designed to test findings and solicit input from interested stakeholders on a range of issues related to the project. Finally, a set of real-world user experience sessions were organised at Ulster University to assess the experience of first-time TRE users. These sessions were designed to assess and compare high-level usability in terms of system familiarity and levels of difficulty experienced when running a defined set of data analysis tasks across two TRE implementations.

In addition to these structured engagements, this report reflects the experiences of the authors, all of whom were part of the SATRE research team work package 5 (WP5). WP5 met online weekly from February to October 2023 and fortnightly with the wider SATRE project team. As part of this work, authors attended various DARE UK project meetings and reviewed written outputs from DARE UK and from across the UK research data infrastructure landscape.

2.   Key themes from SATRE engagements with TRE users

This section comprises of key insights from the SATRE project's engagements with users. We first present the diverse range of users we have defined through our work (2.1), before looking into the reported problem areas, or 'issues', for each group – focusing on 'analyst-researchers' (2.2), and then other users (2.3, 2.4). We then dive into more detail on our user testing sessions for analyst-researchers directly user testing two TREs (2.5).

2.1.   The diverse users of TREs

We define a TRE user as **anyone who has responsibilities for data inside a trusted research environment.** This definition builds on perspectives offered on users in the *DARE UK Blueprint* and from our own structured

engagements with TRE users. From this work we define four types of TRE user which we use to help elaborate the evidence presented in the report. These user types aggregate common skills, knowledge, and dispositions in order to i) aid systematic understanding about how users address data responsibilities within their research environments and ii) aid the design of a standard TRE architecture that addresses these needs.

The user types are broad composites of people, their experiences, roles, motivations, responsibilities, and practices as they work with data using TREs in different organisational and institutional contexts. These user types are based on descriptions provided by people of their own work who engaged with SATRE and are outlined in Table 1.

User type	Description
Analyst-researchers	Analyst-researchers use TREs to do data work. They might collate, ingest and clean data. They will typically run analytical procedures and to varying degrees will communicate analysis to other users and to external stakeholders
Operators	Operators are responsible for the operation, maintenance, and configuration of TREs, ensuring they continue to meet the needs of users, and organisational and institutional stakeholders
Data research managers	Data research managers take charge of directing analyst research activity, from as little as one or two analyst researchers (for instance as part of a small research project) to sometimes as many as hundreds of analysts across many distributed locations, for example, across an NHS Trust or large university. This role may be played by a Principal Investigator or similar.
Information governance users	Managers often have significant information governance responsibilities, although in many large organisations there are specialist information governance users who are responsible for adhering to local and national information governance rules and regulations

Table 1. TRE user types used in this report

In reality, no two users of TREs are quite the same and across our engagements we encountered a broad diversity of TRE users. Diversity between types of users is represented in Table 1, while diversity within each of these types of users, which contributes to a complex ecosystem of people using TREs, is discussed as appropriate in the coming sections. Notable features of this complexity are different aims, responsibilities, and accountabilities of the users we have outlined; different backgrounds, skills and human capabilities between different individuals and roles, and different ways of working and preferences for data analysis and communication.

Among the groups described in Table 1, analyst-researchers are the most typically referred to as users, or the first to be thought of when speaking of users; while other groups find their needs and issues more directly reflected in current discussions, analyst-researchers are typically under-represented in research, in part we suspect because of the complexity involved in standardising data research infrastructure that addresses their needs. The primary focus in this report then is analyst-researchers. [2]

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[2] A pragmatic definition of users who matter in any given TRE may vary. Because the focus of the SATRE project is on providing a standardised architecture, we consider a broad set of users who potentially span organisations. However more narrowly defined users in some cases may be just those using the TRE for data analysis. Operators might be defined as extra-organisational service providers for example.

2.2. Issues amongst analyst-researchers

For these analyst-researchers, regular TRE tasks may include logging onto TREs using VPNs and virtual machines, running analysis using software such as R, Python, Excel, and MS SQL Server, ingesting data or requesting colleagues to ingest or link data on their behalf.

Examples of analyst-researchers that participated in our engagements include an expert in clinical risk prediction modelling, a PhD student in health informatics and a self-described data-wrangler working on tools for early detection of neurodegenerative disease at a large interdisciplinary data institute. We also talked to research managers, principal investigators, and others with line-managing responsibilities for analyst-researchers. In the following insights we avoid prioritising issue importance as what matters most to users often depends on specific contextual factors such as the size of the host organisation, maturity of the TRE infrastructure or experience of the TRE workforce, resources available to support users, and the institutional aspects of the data tasks.

This section is based on self-reported issues faced by these users. For a direct exploration of user experience within TREs, go to section 2.5.

2.2.1. Hands-on experiences: frustrations and benefits

Common concerns shared by many analyst-researchers include frustrations with slow research environments and computers, uncertainty, and lack of clarity about how to seek help from organisational colleagues on technical matters related to their TRE use when needed. Slow or intermittent internet connectivity was also an issue for some when accessing remote virtual machines. Some users also spoke of frustrations with what they perceive as slow decision-making processes by their organisation when it comes to managing technical change requests on their TREs, for instance the installation of new analytic packages for R. On the flip side, having a full suite of analytic tools as well as data and computational power readily available in one place was seen as a big advantage. Finally, frustration for users grew when they didn't agree with, or didn't understand, the rationale for some procedures. For example, one user told us they were frustrated that they had to delete data and re-install research environments from scratch at the end and then beginning of research projects.

We recommend:	
R2.1	TRE teams provide as comprehensive a suite of analytic tools, data required for the research being undertaken, and accessible computational power as possible as a default within their TREs.

2.2.2. The need to gain familiarity using specific TREs

User experience isn't just about being able to use the environment, but also the process of onboarding, knowing how to access data and finding your way around the TRE. Gaining competence in any practice involves achieving familiarity with tools and surroundings. Observing analyst-researchers using specific TREs for the first time, it took some time for users to become comfortable with their new research environments. This is an important observation for infrastructure designers – good infrastructure is unobtrusive, friction can be the sign of poor user experience. We liken this experience to the challenge of configuring a new laptop. The most important tools are often up and running in minutes or hours, but it can take days or even weeks before a computer truly feels like home - with tools and packages configured and data ready at hand. TREs, especially those that function primarily through virtual machines and desktops, are the same.

Some long-time TRE users told us that because TREs are not standardised at present, they have concerns about the need to gain familiarity every time they have to access a TRE that is new to them. Users also have to learn different ways of working depending on TRE design and configuration choices made on specific instances. A critical aspect of gaining familiarity is knowing where things are.

We recommend:	
R2.2	TREs should clearly list available tools and information about the data that TREs hold, and make this information available to users.

2.2.3. Support, learning and customised environment configuration

One form of support that can help building usable knowledge of TREs is documentation. Although providing documentation is useful, it's not always read. Gaining knowledge through formal means such as training is valued by some users, but for many, building everyday tacit knowledge through direct experiences (in live environments or in specially commissioned sandboxes) is important too. Users report different ways of working and learning. This suggests that onboarding and ongoing support might offer forms of hands-on or peer support in addition to asynchronous methods such as documentation and video tutorials. To this end, one contributor told us about co-piloting services run at their organisation where a real person helps with initial project tasks, a service which can be tailored to users' needs.

Some users told us that they often don't understand or aren't aware of support already available to them. This can be about technical issues within the TRE, but analyst-researchers can also need information on organisational processes, for instance about information governance or best practice.

We recommend:	
R2.3	TRE teams making clear to analyst researchers the TRE support offered by their organisation, and possible options for building skills and capabilities, for instance though sandboxes or co-piloting.

2.2.4. Collaboration

Analyst-researchers typically work in teams. Communicating outputs, analysis and results quickly to fellow analyst-researchers and other stakeholders is an integral part of the job. Preferred methods for doing this often involve enterprise applications such as Microsoft Outlook, Microsoft Teams, GitHub, Microsoft SharePoint, Microsoft Word and Overleaf. While users did not necessarily expect TREs to support these kinds of tools, they were nevertheless often frustrated when access was prohibited. The point here is that the provision of tools and procedures for non-analytic tasks such as collaboration, ingesting, and exporting data are as significant as providing analytic tools. Moreover, the familiarity of these tools is often an important factor for users.

We recommend:	
R2.4	Tools and packages for collaboration within TREs should be as familiar to users as possible.

2.2.5. Other recommendations

In summary, analyst-researcher perspectives on usability tended to centre on having a common set of the most useful statistical software packages available and easily configurable on TREs. In one Collaboration Café for instance a participant told us that standards shouldn't be too restrictive on requirements around tools. Where TRE restrictions do impinge on the expectations of analyst-researchers, or what we refer to as mental maps in section 2.5, mitigation measures should include a mix of documentation, training, support and explanation.

We recommend:	
R2.5	TREs have a common set of the most useful statistical software packages available and easily configurable within the environment

R2.6	Users have the ability to use specific commercial software where applicable and version control, easily link data together within the environment and standard ways to identify data across packages
R2.7	Specific methods of teaching are matched to people's learning needs. This is important because simply making documentation available is not sufficient to onboard all users.
R2.8	TREs have a common set of the most useful statistical software packages available and easily configurable within the environment

2.3.   Issues amongst TRE operators

Examples of TRE operators, data research managers, and information governance professionals that participated in our engagements include a head of a data science unit working on dozens of projects at once, a senior data science manager in a large university health science department along with participants who had cross-organisational operation responsibilities. Whereas many analyst-researchers used TREs because they had to, operator users, data research managers and IG professionals are often involved in choosing to use TREs and how they will be used – they want to drive and support TRE use in their organisation.

2.3.1.   Operating TREs in large organisations

TRE use for operators and managers brings with it organisational complexity at scale. Every analyst-researcher user of a TRE will need to be accredited, registered, and supported in different ways. Operators at large organisations will be responsible for sometimes hundreds of users whose projects will need to remain live or archived within secure infrastructure for up to a decade after projects end. In managing these infrastructures, operators face decisions about what kind of support can be automated and what needs to be more hands-on. Within large organisations, TREs and equivalent infrastructure can require ten or more full-time equivalent roles. A concern for some participants in our engagements was the need to transition their research infrastructure from Data Safe Havens to Trusted Research Environments or implement standardised features on existing TREs. For these reasons and others, adequate understanding of how analyst-researchers use their systems is critical for supporting them through any such transition.

Operators and analyst-researchers reported concerns about appropriate operational support and learning. It is likely support needs will change over time. One reason for this mentioned by some participants is that increasing access to TREs for relatively low-skilled users will increase burdens on operators. Operators may have to choose between increasing access (in terms of number of users or access rights for some of those users) and thus increasing support to those users versus restricting access to only analyst-researchers they deem to meet a given proficiency threshold and potentially creating bottlenecks elsewhere in organisations.

We recommend:	
R2.9	User journey pipelines for TRE teams are clearly elaborated and understood, before any users are onboarded.
R2.10	Following the creation of user journey pipelines, operators should maximise the automation of support processes to alleviate burdens that come with scaling users.
R2.11	TRE operators work with DARE UK and other stakeholders to investigate the following questions in the course of future work: what measures can operators use to evaluate the proficiency of their analyst-researchers; how should proficiency threshold levels be established; how do operators design and implement processes and policies that accord with analyst-researcher skills and information governance requirements.
R2.12	User journey pipelines for TRE teams are clearly elaborated and understood, before any users are onboarded.

| R2.13 | Following the creation of user journey pipelines, operators should maximise the automation of support processes to alleviate burdens that come with scaling users. |

2.4. Data research managers and financial concerns

2.4.1. Challenges faced by data research managers

Users who manage other TRE users reported a set of distinct challenges. Research managers brought up issues that touch on different points across the lifecycle of research projects, from bid and grant writing, to setup, to running and coordinating multiple projects to reporting and then safely archiving data and analysis. Research managers are often principal or co-investigators on research bids or charged with managing people and finances in organisations. Some reported that discussions about the need to use TREs often came towards the end of grant writing processes. Earlier engagement when thinking about TREs would make the setup phase of projects more straightforward. By way of example, a problem in one organisation was that specific staff had to be named researchers on bids in order to avoid lengthy administration processes when authenticating and onboarding users. Another example given was that the full costs of using TREs are often externalised at the point of grant writing and become clear only in use. The issue of ethical approval also intersected with these concerns to the extent that delays in ethics approval had knock on impacts on TRE use and in some cases force research managers to change the kind of research question being asked. Finally, research managers also reported frustrations arising when conflicts with existing robustness and quality checks such as peer review were created due to TRE functionality.

We recommend:	
R2.14	Research data managers engage early with questions of costing and scoping TRE use which will make the setup phase of projects more straightforward.
R2.15	Research data managers ensure ethics approval regarding TREs is fully understood before grant submission.
R2.16	Research data managers ensure costs are understood at grant submission time.
R2.17	Research data managers work with operators to ensure TRE provision does not conflict with pre-existing research standards that teams will follow, for instance peer review.

2.4.2. Financial concerns

Financial concerns were raised by several different kinds of users. Operators for instance were concerned about how they might cost strategies that accomplish the training, support and proficiency evaluation issues discussed in Section 2.3.1. One of the issues here is that the costs of implementing, migrating to, or supporting TREs are often carried in different parts of an organisation's budget to where the value of secure and trustworthy data are realised. Data research managers and analyst-researchers in universities for instance typically budget against research income on a per project basis. Budget lines for operators in universities or elsewhere may run on annual or quarterly bases. Furthermore, when it came to issues like setting up users on TREs, scoping support needs and long-term archiving, some participants thought that using TREs led to costs that went beyond what many data scientists were used to. One issue that's at stake here is that the costs of doing research on sensitive data are not always fully booked by the research project. Costs and burdens are externalised across the organisation causing tensions. One research manager told us that in a perfect world project leaders and principal investigators would better consider the entire data lifecycle costs much earlier in the process of planning or bidding for research.

We recommend:	
R2.18	Teams establish costing strategies which define where different intra-organisational costs related to TRE use should be incurred.
R2.19	Any costing strategies teams develop should differentiate fixed costs (of the underlying infrastructure) and variable costs (of ebbing/flowing users and projects), and be flexible enough to allow provision of more or less projects and users.

2.5. Lessons from direct user testing sessions

2.5.1. Reporting user experience testing sessions at Ulster University

A TRE user experience evaluation session was conducted in August 2023. Seven participants were recruited from the Intelligent Systems Research Centre in Ulster University. As part of the session users were asked to complete a data analysis task on the Turing Safe Haven TRE and the University of Dundee TREEHOOSE TRE environments. Prior to the session, participants completed a survey related to their previous experiences of TREs and related concepts. After each session participants were asked questions related to their experience of completing the data analysis activity. Experiments were conducted in a usability lab environment with the session supervisor present. The participants' activities were recorded using screen capture software. Participants were also encouraged to complete the session as a think aloud commentary and audio was recorded. Each participant evaluated both TRE environments, with the order of presentation alternating for each session.

2.5.2. Task Description

Each TRE was pre-configured for use by an analyst-researcher and as such was pre-loaded with data to be analysed and corresponding RStudio and JupyterLab data science notebooks.[3] The user documentation for each TRE environment was also made available as a tab in the internet browser. The overall aim of the task was for the participant to run the notebook and prepare the output file to be taken out of the environment. To complete the task participants needed to complete the following sub-tasks:

- Login and access TRE workspace
- Find data/CSV file and notebook to analyse
- Run existing provided notebook
- Submit an output using the egress/disclosure control functionality
- Safely log out of the environment

2.5.3. Pre-session survey findings

We asked the participants about their knowledge of TREs prior to the session to establish background knowledge. Six participants indicated they had no prior knowledge of a TRE, with one participant indicating they had above average experience of a TRE. We also sought to understand how familiar the participants were with different operating systems (OS) given that the Turing Safe Haven TRE uses a Linux OS environment and the University of Dundee TREEHOOSE TRE uses Windows OS environment. When asked about prior knowledge of Windows OS, five participants reported an average or above level of experience of the Windows operating system, one participant had below average level of experience and one participant reported no experience of Windows OS. When asked about knowledge of Linux OS, four participants reported an average or above level of experience of the Linux operating system, one participant had below average, and two participants reported no experience of Linux OS. Both TREs were pre-configured with RStudio and JupyterLab, which are considered standard data science tools,

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[3] The tasks were adapted from the Data Safe Haven Example Challenge here: https://alan-turing-institute.github.io/TRE-example-challenge/challenge/

allowing the participants to select their preferred tool to perform the data analysis activity. At the pre-session stage, we sought to understand the participants general familiarity with data science tools, rather than specific software which could change depending on the deployed TRE. Considering data science tools, one participant reported a high level of experience, four participants reported above average experience, one participant reported below average experience and one reported no experience. Overall, the participants had a good broad range of experience in using different operating systems, data science tools and programming environments, but little prior knowledge of TREs before the session.

2.5.4. Post-session survey findings

We asked the participants a range of questions relating to their experience when conducting the experiments using the two TREs. Each question had a Likert scale from 1 to 5, where 1 implies knowledge or ease of use and 5 implies no knowledge or difficult to ease. The average responses across 7 participants are presents in Table 2, where a value closest to 1 is best.

Task	Dundee TREEHOOSE TRE	Turing Safe Haven TRE
Familiarity of the working environment	**2.71**	**2.71**
Overall experience of completing the task	2.57	**2.14**
Experience of logging in to TRE	2.43	**2.14**
Experience of finding the data to be analysed	**1.43**	2.14
Experience of running the provided notebook	1.86	**1.29**
Experience of submitting the data for output	2	**1.86**
Experience of logging out of TRE	**1.57**	**1.57**

Table 2. Average responses for post-session survey

2.5.5. Experiment observations

2.5.5.1. Navigating the environments

A mental model is based on what a user believes rather than objective facts. The initial formation of a mental model related to TREs can be a challenge for most new users as they have very little pre-existing knowledge of a TRE other than what the term "Trusted Research Environment" conveys. In 2010 Nielsen reported[4] that many novice computer users don't understand the differences between many common features:

- Operating-system windows vs. browser windows
- A window vs. an application
- Icons vs. Applications
- Browser commands vs. native commands in a web-based app
- Local vs. remote ("cloud") info
- Different passwords and log-in options (users often log in to other websites as if they were logging in to their email)
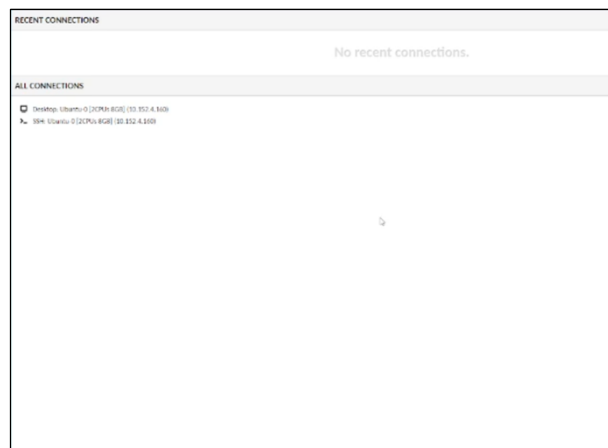
Considering that novice computer users struggle with these concepts, it is not surprising that many novice TRE users struggle in forming a mental model as many of these features are embedded within TRE environments. Experiment participants were consistently observed struggling to understand what to do after logging into both TREs that were evaluated. This can be explained by examining the post-login screens as illustrated in Figure 1.

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[4] https://www.nngroup.com/articles/mental-models/

In the case of the TREEHOOSE TRE (Figure 1(a)) the user is required to navigate to the workspaces icon (bottom icon on left) in order to proceed to the next stage of interacting with the TRE. In the case of the Turing Safe Haven (Figure 1(b)) the user is required to understand the need to click on the one of the two labels presented, in this case the label "Desktop: Ubuntu-0 [2CPUs 8GB] (10.152.4.160)". Without any prior TRE mental model, neither of these interfaces make it intuitive for novice users to understand the next steps without resorting to a trial-and-error approach in order to proceed.

(a) TREEHOOSE TRE interface	(b) Turing SafeHaven TRE Interface

Figure 1. Interface presented to users after logging into (a) TREEHOOSE and (b) Turing Safe Haven.

2.5.5.2.   Locating data to be analysed

This was typically stored in "d:/[study name] in TREEHOOSE and "/Data" in Turing SafeHaven. Users' comments related to locating the data:

- "Unfamiliar with how to find data folder."
- "Found data folder by browsing the filesystem, not the documentation"
- "Documentation helped to find the data."
- "Found the data and notebooks easily as there were not many files and folders."
- "Found data in D drive because it was named data."

2.5.5.3.   Data egress functionality

In TREEHOOSE the user is required to deposit the data in a folder called "d:/egress-store-[random string]" and subsequently need to exit the virtual machine and use the TRE interface to submit the data for egress to receive feedback the egress request has been made, while in Turing Safe Haven the user is required to deposit the data in the "/Output" folder with no other steps or feedback provided.

User comments related to submitting the data for egress:

- "Didn't know if a notification was needed to submit data for egress after data were placed in the folder."
- "Wasn't clear that just putting data into the output folder was enough."
- "While data was submitted to the output folder, I was unsure if another step was needed."
- "Easy to submit but no confirmation to say it's available for egress."
- "Unsure what to do once data were saved. Documents explained where to place data. Assumed there was another confirmation to be completed."
- "I was unsure how to submit for egress."

2.5.5.4. Logging out of TRE

Some users were observed having difficulties in logging out of the TRE and in knowing when they have logged out. Both environments required the user to log out of the virtual computer in the first instance, before then logging out of the TRE environment itself. This is quite counter-intuitive to the mental model users have of logging out of most computer systems.

User comments related to logging out of the systems:

- "Unsure if logged out."
- "Very easy. Easy to find log out button."
- "Still easy to find log out having never used system before."
- "Visually easy to log out from windows."
- "Double log out was needed. Not intuitive."
- "Log out button was as expected and easy to find."

2.5.5.5. Multiple operating systems in view simultaneously.

Another observation was that users often confused the remote desktop environment interface with the desktop environment of the host computer. This was observed with the TREEHOOSE TRE as it runs the Windows operating system, which is the same as the host computer which was used for the experiments. As the Turing SafeHaven uses XFCE in Linux it was more obvious to users which environment was the local and TRE environments.

2.5.6. User experience recommendations

2.5.6.1. Onboarding and documentation

The conceptual leap required for novice users to interact with a TRE is substantial and there are limited examples from other domains that could be used to transfer these concepts. As such it is necessary to ensure that novice users have a comprehensive onboarding process. TRE operators should consider both supervised and pre-recorded training sessions, documentation, and shadowing of existing users.

Both evaluation TREs had detailed documentation available. However, most participants only resorted to reading the documentation when they were unable to proceed. While in all cases the documentation contained the information the participant required, participants often struggled to find the information they needed. In the case of both evaluated environments the documentation included material that was relevant to both analyst-researchers and operators. This was confusing and participants often read lots of information which was not relevant to the task they were trying to complete.

We recommend:	
R2.20	All documentation for using a TRE should be clearly labelled with who the documentation applies to.
R2.21	Where appropriate, documentation should be accompanied by other supporting resources, like tutorial videos and support functions.
R2.22	Documentation should be as minimal as necessary to provide user support, avoiding superfluous information.
R2.23	It is not good enough for TREs to just provide documentation - the documentation must be easy to use and navigate, and up to date.

2.5.6.2. Labelling and signposting

With users having limited opportunities to transfer pre-existing knowledge to TRE environments, there is a need for very clear, consistent and understandable use of labels and signposting. For example, consider when a user is presented with logging into the TRE environments: for TREEHOOSE the user then needs to navigate to Workspaces, find the study and start the virtual environment; for the Turing Safe Haven the user is required click on the label "Desktop: Ubuntu-0 [2CPUs 8GB] (10.152.4.160)". The labels and steps required here are not intuitive to most novice users. In addition, the terminology used in both environments differs and does not align with most users' expectations. Providing guidance on the initial screen to inform users that they can find their studies in the "Workspaces" area would help prompt users on where they need to go. Changing the label "Desktop: Ubuntu-0 [2CPUs 8GB] (10.152.4.160)" to a button labelled, for example, "Start secure remote computer" may allow the user to better understand what they need to do.

We recommend:	
R2.24	Any actions that may seem unintuitive, especially to those unfamiliar with the TRE OS, should be accompanied with supporting labels.
R2.25	If in doubt, labels should be used to direct users in all key actions.
R2.26	Any labels should correspond to the relevant part of accompanying documentation.
R2.27	User testing sessions should focus on user understanding, and highlight where further labels/error handling are required.

2.5.6.3. Future experiments

The experiments uncovered some fundamental usability issues with both TREs, and the evaluation team is not clear about any prior usability testing and evaluation of either TREs.

We recommend:	
R2.28	TRE developers perform a heuristic evaluation to assess usability, for example using Jakob Nielsen's 10 usability heuristics. Heuristic evaluations are useful because they help find usability issues without having to test with participants.
R2.29	A cognitive walkthrough evaluation is done of any newly deployed TRE instance, as this technique can be used to evaluate the learnability of the TREs from the perspective of a new user and can be performed by the developers. Like heuristic evaluations, the cognitive walkthrough relies on the expertise of a set of reviewers who, in a highly structured manner, walk through a task and assess the interface from a new user's perspective.
R2.30	Once any identified usability issues have been addressed using both these methods, end-user evaluation should be done using combinations of formal evaluation techniques such as A-B testing, observation studies and eye-tracking studies, before the TRE is used in production.

3. Sociotechnical understandings of usability and users

Based on the contributions from users presented in Section 2, in this section we make recommendations about how knowledge of users and usability can be produced, and what TRE operators and infrastructure funders need to know. In 3.1 we describe how usability should be understood along both social and technical dimensions. In 3.2 we identify methods and opportunities to learn more about TRE users and in 3.3 we outline implications and recommendations for DARE UK's programme of projects.

3.1. How to understand TRE usability

Our interactions with users also shed light on ways to specify our understanding TRE usability. These contributions show that usability is both a technical property of infrastructure standards and design, and also a sociotechnical characteristic that emerges in specific contexts of use and is influenced by users' needs, existing knowledge, skills and prior experiences.

We recommend:	

R3.1	All future studies follow a sociotechnical approach to usability. This approach should discriminate usability along three dimensions:
	
	   i. The extent to which TREs help users meet organisational responsibilities in doing their job. For instance, role-specific issues of usability such as managing and administrating other TRE users in research groups or across organisations.
	   ii. The extent to which TREs help users meet organisational and institutional accountability obligations including but not limited to information governance.
	   iii. Task-orientated issues of usability. For instance, we described above how analyst-researchers valued usable tools and processes for communication and collaboration in addition to using analytic tools.

3.2. Learning about TRE users to specify and evaluate TRE usability

These sociotechnical dimensions of usability are relevant to this report because they indicate that usability cannot be produced by technical infrastructure that adheres to a standard architecture alone. Usability is also produced through complex and changing social, organisational and regulatory factors. Because of this, it is impossible to precisely specify usability requirements in advance.

This evidence can be produced through studies on the known population of users and through a priori and on-going user testing as indicated in Section 2.5. In Section 2.5.2, we drew attention to issues of onboarding, labelling and signposting critical for increasing the usability of TREs.

We recommend:

- Standard architecture requirements must be complemented with contextual guidance, ideally informed by evidence about a diversity of local users.
- User studies should consider the expectations and experiences of regular TRE users as well as the needs and knowledge of novice and future users.
- User testing should discriminate usability from the perspective of diverse users and against a range of tasks, including analysis and data science tasks as well as administrative and communicative tasks.
- TRE operators should test usability of help desks and automated support services such as ticketing platforms.

We recommend:	
R3.2	Standard architecture requirements must be complemented with contextual guidance, ideally informed by evidence about a diversity of local users.
R3.3	User studies should consider the expectations and experiences of regular TRE users as well as the needs and knowledge of novice and future users.
R3.4	User testing should discriminate usability from the perspective of diverse users and against a range of tasks, including analysis and data science tasks as well as administrative and communicative tasks.

R3.5	TRE operators should test usability of help desks and automated support services such as ticketing platforms.

3.3. Implications for the DARE UK Blueprint

There are several implications for the continuing work of DARE UK. Five projects, including SATRE, were funded as part of DARE UK's Phase 1 Driver Projects phase. Each of the projects has been a nine-month sprint. The focus in each has been on infrastructure (TRE-FX, TELEPORT) and standardisation (SATRE), software development (SACRO), user space tooling (SARA) and demonstration, with insufficient time, understandably, for thinking about usability and user testing.[5] However, as some of these ideas and projects move on, introducing usability perspectives will be critical.

For instance, the TELEPORT project has been working on creating 'pop-up' TRES that federate data from more than one TRE, whilst ensuring information governance compliance with host TREs. A key part of this work is exploring how similar but different approvals processes can be brought together so that the data controllers – the people who are ultimately responsible for the data – can have the confidence it is being used appropriately and securely by researchers and in line with the uses they have approved. Issues of usability and understanding diverse users from across the TRE landscape along with their needs and work practices will be vital for ensuring that the accreditation systems for 'pop-up' TREs are not just safe but also usable, accessible and familiar to a range of users.

A second set of implications for DARE UK's work hinges on the distribution of costs, benefits and support for users across federated systems. It is important that the costs and benefits of usability features (be they improvements or otherwise) are distributed equitably across the federation. A risk in any complex system is that stakeholders in one part of the system end up paying more than their fair share for potential benefits they do not or cannot realise. A practical example is that some TREs do much more work in preparing data (via data cleaning and engineering) for their analyst-researchers than others. Further research is needed to understand competing user practices and expectations within federated systems.

We recommend:	
R3.6	The DARE UK phase 1 driver projects should be reviewed though a usability lens in order to specify agendas for in depth user studies on emerging TRE technologies.
R3.7	Future DARE UK projects must gain insights from real TRE users working on and with real data in real world situations, ideally understanding users through longer term engagements in the order of 2-3 years.
R3.8	To achieve this, projects should build on significant stakeholder engagement by the SATRE team and across DARE UK in order to work with operators, data managers and TRE analyst-researchers.
R3.9	Future projects or work-packages explicitly identify aims and opportunities for comprehensive UX advancements for emerging DARE UK infrastructure and tooling.
R3.10	The costs and benefits of usability features should be distributed equitably across the federation.

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[5] See: **SATRE:** Standardised Architecture for Trusted Research Environments, led by researchers at the University of Dundee;
TRE-FX: Delivering a federated network of trusted research environments to enable safe data analytics, led by researchers at the University of Manchester;
TELEPORT: Connecting researchers to big data at light speed, led by researchers at the University of Swansea;
SARA: Semi-Automated Risk Assessment of Data Provenance and Clinical Free-text in trusted research environments, led by researchers at the University of Edinburgh;
SACRO: Semi-Automated Checking of Research Outputs, led by researchers at the University of the West of England.

4. Usability: A standard architecture principle for TREs

The contributions from users outlined in Section 2 guided our drafting of an initial usability principle within the SATRE Standard Architecture for Trusted Research Environments. Architectural principles influence and shape the way you design and deliver a SATRE-aligned TRE and help set the conditions around which the entire system can be judged. They are a set of guiding considerations that sit above any specific architectural requirement, and can be applied across the entire architecture.

The intention is that this usability principle will contribute to the standard architecture by aligning design and implementation of TREs with the needs, expectations and working practices of diverse users. Ideally, users of specific TREs would be consulted about the extent to which this principle is met for any given implementation.

The usability principle outlined in table 2 was established based on the work that this report represents, versions of which were iterated through discussion at a SATRE Collaboration Café – an online meeting place for stakeholders to collectively discuss and advance aspects of the SATRE specification. Table 2 represents the principle at the time of writing, which is subject to change as the SATRE standard architecture evolves through contributions to its open online repository.[6]

Principle component	
Statement	A TRE instance that works for everyone minimises barriers to use, and provides a productive and accessible analysis environment for research
Rationale	There is often a trade-off between increased operational security and the usability of a TRE. In order to maintain productivity, a TRE must balance these two competing aims. A TRE's design and configuration should allow all individuals involved with a TRE to effectively fulfil their roles.
Implications	• Robust TRE design and implementation should start by understanding users' diverse expectations, needs, existing skillsets and preferences and responsibilities. • Design, configuration and testing of TREs must recognise a diversity of users. For instance, not all users are researchers and not all researchers are users. Other users include TRE operators, information governance officers, and TRE builders/developers. • Because of diverse user needs, it is unlikely that a specific TRE instance will perfectly match the needs of all users. • A TRE that is overly strict on tool and software provision may risk becoming unusable for users with different and varied backgrounds and skillsets. • Working environments can differ significantly from users' preferred setups. This has design and resource implications for supporting new users, and consideration should be given to resources and time required to help users get up to speed with new and unfamiliar TRE instances. • Improving user experience takes time and resources and will involve trade-offs between investing time in improved standards, better functional design, improving work and organisational culture, boosting users' skills and knowledge through training and making help more readily available at an organisational level. These trade-offs will need to be addressed at an organisational level, and teams may want to consider resourcing staff to focus specifically on these questions, for instance in the positions of product managers or service functions.

Table 2. TRE standard architecture principle for usability

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[6] See https://satre-specification.readthedocs.io/en/latest/principles.html for this principle in context of the complete Standard Architecture for TREs. This site includes details of how to contribute to maintaining the open architecture via its GitHub repository.

5. Summary recommendations for research and development

The contributions presented in this report are the result of pilot research necessitated by the SATRE project's goal to develop approaches to evaluating standard architecture TREs in the context of users, amongst a range of other phenomena. The sprint-like nature of the UK DARE Driver Programme phase 1 and the SATRE project meant that these contributions are methodologically compact and empirically succinct. For instance, user testing and engagements took place only on a small number of TREs. Moreover, user testing standards such as those we are building in SATRE is difficult as the specification is capability-based rather than being built around specific features and experiences which can be the subject of specific tests. However, this report demonstrates the need for further user research not least because infrastructures are designed to last. Decisions about how they are standardised and evaluated today will impact a generation of TRE users. Centring users in TRE development strategies now will benefit operators and funders of TREs enormously for years to come.

DARE UK is well placed to drive and coordinate this work as a standalone project or more likely, as a series of major work packages in larger, longer-term projects. Given the planned growth in TREs and other kinds of large data platforms across public, industrial and research sectors in the UK, this work is now urgent. In this report we have highlighted some surprising and perhaps some not surprising areas for immediate investigation. For instance, participants in our Ulster University user testing sessions reported high capability in terms of using Linux for the first time. At the same time, they reported low capability in terms of completing what might have seemed at the outset straightforward tasks like egressing files. Future research must better understand users' expectations and mental maps of TREs. Research is also needed to create understanding about the workflow of users, what they gain and lose from using a TRE and how their tasks, roles, and jobs are changing as a result.

The wider point here is that many technical solutions have been designed and built during the DARE UK Driver Programme. Given the time constraints it was not possible to adequately consider user experience. However, building on the significant stakeholder engagement by the SATRE team and across DARE UK, future work must engage operators, data managers and TRE analyst-researchers to identify comprehensive improvements in UX for tooling, infrastructure, and standards and in order to fill gaps in knowledge identified throughout this report.

Finally, entirely out of scope for this pilot work were questions of fostering trustworthy research culture within infrastructures. As trustworthy research infrastructures scale, the issue of how changing technologies and organisational dynamics shape research culture – that is the practices that are valued in and by individual users and research communities – is likely to be a significant one. Afterall, trustworthiness is an emergent property that is shaped by the public's ongoing and changing relationship to infrastructure and the organisations and people who operate them. We strongly recommend a research project or work package focussed on infrastructural organisations, their people and cultures as part of future DARE UK programmes. Such studies should systematically investigate how future TREs can cultivate trustworthiness through infrastructures that empower users and safe user practices.

We recommend:	
R5.1	Research and development on TRE usability engage with operators, data managers and TRE analyst-researchers to identify comprehensive improvements in UX for tooling, infrastructure and standards as well as communications and user support. This work must better understand users' expectations and mental maps of TREs as well as their needs
R5.2	Work packages are funded focused on producing knowledge about users' workflows and what they perceive as gaining and losing by using TREs, as well as understanding how users' tasks, roles, and jobs are changing as a result of TRE use. This has important ramifications for job satisfaction, well-being and training.

UKRI UK Research and Innovation   HDRUK Health Data Research UK   ADR UK

R5.3	Research on safe and trustworthy research culture is carried out to better understand the role of users within organisations and how user roles and practices are being re-shaped by changing infrastructures.
R5.4	A major piece of research focussed on how long-term research cultures are shaped by evolving trustworthy research infrastructures and the organisations that run them. This work will look at the role of people within cultures and organisation, their career pathways, and how they can be empowered to do safe and trustworthy work with data.

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Versions:
Version 1.0: 2023-10-30, original publication.
Version 1.01: 2023-11-02, this version. Updated formatting of recommendations; text edited for grammar and consistency