The Alchemy of Trust: The Creative Act of Designing Trustworthy Socio-Technical Systems

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Trust is recognised as a significant and valuable component of socio-technical systems, facilitating numerous important benefits. Many trust models have been created throughout various streams of literature, describing trust for different stakeholders in different contexts. However, when designing a system with multiple stakeholders in their multiple contexts, how does one decide which trust model(s) to apply? And furthermore, how does one go from selecting a model or models to translating those into design? We review and analyse two prominent trust models, and apply them to the design of a trustworthy socio-technical system, namely virtual research environments. We show that a singular model cannot easily be imported and directly implemented into the design of such a system. We introduce the concept of alchemy as the most apt characterization of a successful design process, illustrating the need for designers to engage with the richness of the trust landscape and creatively experiment with components from multiple models to create the perfect blend for their context. We provide a demonstrative case study illustrating the process through which designers of socio-technical systems can become alchemists of trust.

CCS Concepts: • **Human-centered computing → HCI theory, concepts and models**; **Computer supported cooperative work**.

Additional Key Words and Phrases: Trust, Socio-Technical Systems, System Design, Virtual Research Environments, Transdisciplinary Research, Information Systems

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1 INTRODUCTION

Collaboration and decision-making are key aspects of the transdisciplinary research landscape, wherein multiple disciplines and stakeholders seek to address complex and wide-ranging problems. To facilitate said research, fostering (well-placed) trust is essential [99] for facilitating and sustaining collaborative relationships [27, 45, 58, 76, 80, 82, 84] and reducing complexity and managing uncertainty [5, 27, 70, 73, 76, 100]. Yet, trust (and the study of it) is deceptively slippery: it is an intuitive and everyday fact of life [73], yet also *elusive* [14]. 'Trust' describes a phenomenon that has a great deal of subtle variance, complexity, and nuance: "scholars tend to mention trust in passing, to allude to it as a fundamental ingredient or lubricant, an unavoidable dimension of social interaction, only to move on to deal with less intractable matters" [40, pp. ix-x]. Similarly, Porter et al. (1975, p.497 as cited in [79, p. 24]) note that trust is "widely talked about, and it is assumed to be good" yet when it comes to "specifying just what it means [..] vagueness creeps in". However it is precisely these 'vague' and 'intractable matters' which designers must contend with if they are to design a trustworthy system.

The paper emanates from our research into and experiences of designing a virtual research environment in a transdisciplinary science setting [114]. Virtual research environments [15, 25] (also referred to as digital libraries [116], collaboratories [10, 18] and virtual labs [49]) provide the resources of traditional data repositories alongside additional functionality, including access to software and tools for analysing and presenting data [6, 23, 49] and support for social interactions [4]. In their roles as infrastructures to support grand transdisciplinary challenges [11, 34, 53], these systems must be designed to fit the needs of multiple communities [6] and facilitate multiple kinds of use [23] for present, known users and future, unknown users often distributed geographically, temporally, and disciplinarily [7, 16, 34, 125].

Trust has been approached, defined, and modelled in many ways within many disciplines [12, 58, 69, 77, 82, 105, 107, 123], yet is typically modelled between actors in the form of interpersonal trust. In our efforts to design a trustworthy socio-technical system there are few specific models or approaches we can look towards [51], conceptual frameworks to follow [41], or specific design principles to draw upon [59]. Moreover, simply knowing the "ingredients of trust does not unlock the recipe for trust" (Parkhe, 1993 as cited in [12, p. 271]). One must, as a designer, creatively adapt existing trust models to successfully design. We found ourselves asking, *if you're designing a system with multiple stakeholders in their multiple contexts, how do you combine these trust models?* Following this, even when a model has been identified, *how does one go from selecting a model or models to translating those into design?* We contend that in order to effectively design a trustworthy socio-technical system, designers have to become *alchemists of trust*. By this we mean that they must pull together ingredients that when combined produce trust by creatively adapting existing trust models and, further, translating them into practical design.

This paper demonstrates the practice of invoking alchemy and provides an overview of our endeavour to design a trustworthy socio-technical system. We review and analyse two models of trust (Sect. 2) applying them to virtual research environments (Sect. 3). We show that each model returns different results, and that we need to think about combining elements of these into an ensemble model. Finally, we discuss the benefits and limitations of this approach (Sect. 4) and conclude with some thoughts on the applicability of alchemy and the translation of models into practice. Our research contributes to matters of trust in the design of socio-technical systems in three ways:

(1) We draw upon social science and philosophy, providing a clear description and analysis of trust models and their components to afford greater clarity regarding the many relevant considerations when designing trustworthy socio-technical systems.
(2) We apply these models to our context of virtual research environments, illustrating that it is possible — and beneficial — to deliberately account for the complexities of trust.
(3) We propose "alchemy" as a useful metaphor to convey the need for designers to creatively combine multiple trust models (or components thereof), using these models to seed thinking about different dimensions of trust.

2 MODELS OF TRUST

Trust is considered a fundamental element of the relationship between people and technology [20], yet 'online' trust is different to 'offline' trust (i.e., real-time interpersonal human-to-human trust) [20, 21, 92, 109]. Whether a socio-technical system as a technology can be trusted is debated [82, 99] because technologies and systems are not volitional moral agents and so cannot have intentions and free will [21, 37, 81, 101, 113] – a key requisite of many definitions of trust (cf. [78]). However, many state that we can in fact trust technology [1, 17, 56, 60, 66, 68, 77, 81, 107, 108, 111] as technologies are often perceived — and responded to — as social actors [66, 68, 90], and socio-technical systems include not only the technological system itself, but also the organisations, communities, and individual actors surrounding the system, that trust can be placed in [30, 101] and which contribute to the development of trust [58, 68, 76, 77, 118]. As described in the Introduction, there are no pre-existing models that we can draw upon in our specific context of designing a virtual research environment for transdisciplinary science, therefore we look towards models which account for the varying trustees within a socio-technical system. A wide array of trust models exist, of which several models were considered before utilising the classification for models proposed by Sollner et al. [107], which delineates models based on the object in which trust is placed, either trust in a person or in a system [107, Fig. 1, p. 2]. Based upon this classification we select two well-cited models that speak to our design goal — considering a virtual research environment as a *mediator* where user-user trust relationships are mediated through the technology and as a *trustee* where the technology itself is trusted [107]. For the mediator role, we use the model by Riegelsberger et al. [99, Fig. 5, p. 399] and for the trustee role, the model developed by McKnight et al. [81, Fig. 2, p. 12]. These models are differentiated by the trust that they model, i.e., trust in other users mediated by a system, and trust in the system itself thus focusing on different aspects of trust in socio-technical systems. In the remainder of this section we describe these trust models and their components and begin to apply them to our context.

2.1 Mediator Role

The *mediator role* focuses on trust between users mediated by technology [107] (e.g., computer-mediated communication) resembling interpersonal trust in an online environment. For the mediator trust role, we utilise the model developed by Riegelsberger et al. [36, 97–99] which is based upon the ABI model of interpersonal trust within organisations developed by Mayer et al. [78]. The ABI model — which includes propensity to trust, perceptions of trustworthiness, willingness to be vulnerable, and factors of perceived trustworthiness (i.e. the characteristics of the trustee are 'ability', 'benevolence', and 'integrity') — has been highly cited and widely used [71, 82], including: the addition of predictability [26, 43] and of transparency and identification [93]; and has been applied to: AI [115], online recommendation agents [9], computer-mediated communication [36, 97–99], digital information [56], and to model trust in technology based upon user perceptions of a technology as exhibiting more human-like than system-like features [66].

Regarding trust in technology, Riegelsberger et al. state that, "in addressing these concerns we incorporate trust in technology in our framework, but we restrict its applicability for technological trustees to the property ability rather than motivation. In many cases trust in technology will be linked to trust in the socio-technical systems which this technology is part of. The full framework can be used to analyze these systems" [99, p. 388]. Thus, this model is potentially well-suited to the design of transdisciplinary virtual research environments as a socio-technical system, allowing a consideration of factors beyond ability.

2.1.1 Model Components. The trust model developed by Riegelsberger et al. [36, 97–99] combines two *intrinsic properties* of a trustee — ability and motivation (based on internalized norms (integrity) and benevolence [78]) — alongside *contextual properties* (motivation based on temporal, social, and institutional embeddedness) proposing that in combination these properties form the basis of trustworthy behaviour [36, 99]. Intrinsic properties are relatively stable attributes of a trustee (*ability* and *motivation*), and also of the trustor, e.g. propensity to trust and take risks [36, 98, 99]. *Ability* has domain-specific (e.g., technical knowledge) and general components (e.g., intelligence) [99]. This mirrors Mayer et al.'s ability characteristic which pertains to the "skills, competencies, and characteristics that enable a party to have influence within some specific domain" [78, p. 717]. Ability is domain-specific as a trustee may have a high competency or skillset to do a specific task which may not translate to another task, for which they "may have little aptitude, training, or experience" [78, p. 717]. *Motivation* is divided into benevolence (related to affective trust) and internalised norms (related to cognitive trust) [97]. *Benevolence*, as in Mayer et al.'s model [78], refers to the relationship between a trustor and trustee [99], reflecting "the extent to which a trustee is believed to want to do good to the trustor, aside from an egocentric profit motive" [78, p. 718]. *Internalised norms* (also referred to as 'dependability' [97]) refers to the perception by the trustor that the trustee acts in line with the principles, internalised codes of conduct, norms and values which they claim to act on [97, 99], bearing similarity to 'integrity' [78].

To this, Riegelsberger et al. also include *contextual properties*, building upon Mayer et al., who noted that "the specific consequences of trust will be determined by contextual factors such as the stakes involved" [78, p. 726]. Contextual properties provide both positive and negative incentives for trustors and trustees [98, 99]. For instance, *temporal embeddedness* occurs if there are stable identities, and the trustee has reason to believe that they will interact again in the future and be recognisable [98, 99]. Membership of a community or organisation also support trustworthy behaviour and is 'institutionally assured' because of the likelihood of further encounters [99]. *Social embeddedness* refers to a trustee's performance and reputation regarding their honesty, reliability, or dependability and can provide an incentive to fulfil (even without prospect of specific future interaction) because they are socially embedded within a community or organisation and thus reputation is important as it can potentially affect their standing [99]. Finally, *institutional embeddedness* reflects the influence on the behaviour of trustees by institutions or organisations, including wider networks and third parties [98, 99].

The model proposed by Riegelsberger et al. is similar to the model by Mayer et al., as the dynamism of trust is reflected, e.g., ability will change as situation and task change, and reflects the multidimensionality of trust. Both models also consider the development of trust. Mayer et al. propose that integrity and propensity to trust are important at earlier stages of a trust relationship where there may be little to no direct information or interaction ('initial trust'). They then go on to suggest that benevolence may be important as the relationship develops ('continuous trust'), "thus, the development of the relationship is likely to alter the relative importance of the factors of trustworthiness" [78, p. 722]. Riegelsberger et al. too refer their model to the development of trust, "in first-time or one-time interactions, the signalling of trust-warranting intrinsic and contextual properties is particularly important because no previous experience with a trustee is available. In repeated exchanges, it becomes important to signal identity, as this allows the trustor to extrapolate from knowledge about the trustor that was accumulated in previous encounters" [99, p. 391]. However, the model by Riegelsberger et al. also departs from the earlier model by Mayer et al., in terms of the trustee. Mayer et al., define trust as "applicable to a relationship with another identifiable party who is perceived to act and react with volition toward the trustor" [78, p. 712] — in computer-mediated communication settings, a trustee may or may not be known, as is the case in the transdisciplinary research setting we are designing for.

2.2 Trustee Role

In contrast to mediator role trust models, *trustee role* trust models do not take an interpersonal trust route, instead focusing specifically on trust in technology in a user-system relationship [21, 66, 68, 81, 107]. The models by Lee, Moray, and See [67, 68, 89]; Corritore et al. [21]; and McKnight et al. [81] are prominent models in this area that fit into the classification of trust models developed by Sollner et al. [107]. We focus on the model proposed by McKnight et al. [81], as it is more appropriate to our setting, in comparison to automative technology, which is programmed to complete certain tasks (cf. [68]). McKnight et al.'s model has also been used by Lankton et al. [66] to form 'system-like' trust in technology constructs based upon users' perceptions of system features, and, whilst not directly building on the ABI model [78] like the mediator role trust model, this model has been compared in terms of trustee characteristics (Sect. 2.2.1).

2.2.1 Model Components. McKnight et al.'s model consists of: propensity to trust general technology (consisting of 'trusting stance' and 'faith in humanity'), institution-based trust in technology ('structural assurance' and 'situational normality'), and trust in a specific technology ('functionality', 'helpfulness' and 'reliability') [81]. They note that, based on existing trust literature, there is potentially a causal ordering where propensity to trust influences institution-based trust and indirectly influences trust in a specific technology [81]. *Propensity to trust* is a willingness to depend on a technology across situations and technologies. *Institution-based trust* consists of *structural assurance*, the belief that appropriate structures such as guarantees, legal and technical measures are in place [81, 82, 105, 126], and *situational normality* that the system is functioning in a predictable, normal and well-ordered way such that one can extend trust to something new in the situation and that taking a risk will lead to a successful outcome [3, 70, 73, 81, 82]. In the context of their model, McKnight et al. note that institution-based trust refers to beliefs about a specific class of technologies (rather than a specific type or instance) within a specific context and focuses on the belief that success is likely because of supportive situations and structures tied to a specific context or a class of trustees: *technological situational normality* posits that in a normal and well-ordered scenario, a person can extend trust to something new, e.g. when one feels comfortable with the class of technology and *technological structural assurance* that the structural conditions exist to make success with the technology likely regardless of the characteristics of the specific technology [81]. Finally, McKnight et al. [81] include *trusting beliefs in a specific technology* which are trustee-specific and based on a relationship with a particular technology.

Trusting beliefs about the favourable attributes of a specific technology are "directly derived from, and are corollaries to, the human-like trust attributes of integrity, competence, and benevolence" yet "are less likely to violate humans' understanding of a technology's capabilities" [66, p. 883]. *Functionality* refers to the belief that the specific technology has the capability, functionality, or features to complete a task. It is similar to 'ability' [78], assessing the trustee's ability to fulfil a promise, because "they represent users' expectations about the trustee's capability" [81, p. 5]. *Helpfulness* refers to the belief that the specific technology provides adequate, effective, and responsive help for users when needed, bearing similarity to 'benevolence' [78] but excluding moral agency and volition [81]. Finally, *reliability* refers to continuous, reliable operation and predictable response [81]. McKnight et al. state that in both trust in people and trust in technology, "we hope trustees are consistent, predictable, or reliable" [81, p. 5], with the distinction being that technology doesn't have volition, but may still have flaws or failures. In sum, "these three beliefs reflect the essence of trust in a specific technology because they represent knowledge that users have cultivated by interacting with a technology in different contexts, gathering data on its available features, and noticing how it responds" [81, p. 9]. They note that these are perceptual beliefs, rather than objective characteristics [81]. McKnight et al. [81] conduct a statistical methodology to validate their model, finding that institution-based trust did not fully mediate the effect of propensity to trust, which had significant direct effects on trust in specific technology.

2.3 Trust Models and Socio-Technical Systems

Viewing a virtual research environment as a socio-technical system, including technical, social, and cultural factors [2, 8, 17, 24, 55, 99], we need to design for potentially competing interests found within a transdisciplinary research setting [59, 93, 104, 114, 117]. However, because trust is emergent for users and their changing contexts, it is dynamic and complex and there is 'no one size fits all' approach [17, 28, 46, 59, 66, 69, 76–78, 81, 87, 100, 102, 103]. Trust in data, trust in systems, and trust in people are all interrelated [52, 57, 59, 76], but it remains unclear how trust in people (e.g. system designers) either play a role in or mediate trust in systems [17, 56, 60, 76, 81]. Trust in a virtual research environment includes trust in: the data, models and information within; the users and stakeholders associated with the system; and trust in the virtual research environment itself.

2.3.1 Trust in Data. Records, data and documents can be trusted themselves, or be instruments used in order *to* trust [47, 56, 104, 110]. Digital information may be evaluated in terms of accuracy, objectivity, validity (soundness and verifiability) and stability (predictability and persistency) [56], or in terms of credibility: honesty, expertise, predictability, and reputation [21]. The ways at which data consumers arrive at their placement or refusal of trust in data are many and varied, consisting of: metadata and supplementary information, the identity of the data producer, the source of the data, community membership, recommendation and reputation, and their own experiences and understanding of the data [13, 31–33, 35, 47, 53, 76, 91, 112, 116, 122, 123, 125]. Some of these means of assessment are reliant upon some background knowledge or experience with the data producer or discipline. However, when trusting in data — and particularly in transdisciplinary research — it may also be the case that the source or contributor of the data are unique, aggregated, or unknown, making it difficult to base trust upon identity [73], e.g. to perceive shared orientations and values. In these scenarios, some forms of continuity may instead be helpful in placing trust [19]. The issue with this however is that trust in data may not have the assurance of consistency or continuity that is needed; however, virtual research environments themselves can potentially provide some type of identity or continuity.

2.3.2 Trust in People. Trust in people can be considered in terms of development: *initial trust* occurs before interaction based on indirect, second-hand information e.g., reputation; experience with similar situations, e.g., another individual from the same organisation; or cognitive cues, e.g., categorisation [5, 71, 80, 82–84] and *continuous trust* based on a direct experience or familiarity with the trustee and repeated interaction over time [48, 69, 100]. In a virtual research environment it may be the case that both types of interpersonal trust exist simultaneously for different users. Reputation, knowledge communities, institutional affiliation and past experience may be utilised to establish competence, commitment, and credibility and hence trust in other people [21, 33, 56, 112, 116]. However, this can be challenging online, particularly if a stakeholder does not have any experiential knowledge or prior interactions with others in the community. Trusting in people in these environments can have higher risk and uncertainty, as normal social cues are absent and we cannot see others' actions as we are able to in offline environments [29, 42, 73]. Mechanisms to foster trust in people — both known and unknown — can therefore be beneficial, and can aid with other forms of trust, e.g., trust in data as discussed above.

2.3.3 Trust in Systems. Information technology is different to the information itself [77], and for some users the role of the information provider may be either the data producer or the virtual research environment. Virtual research environments can be a source of trustworthiness [75, 123], by providing continuity and a sense of identity ('trust in people' and 'trust in data'). Yoon [122] suggests that: organizational attributes, user communities (recommendations and frequent use), past experiences, repository processes (documentation, data cleaning, and quality checking), and users' perception of the repository roles all have an influence in the development of users' trust in repositories. Others, such as Knowles et al. [58], have delineated key principles for a 'trustworthy by design' system where security, performance, provenance, translucency, flexibility, value to users, empowerment, and competence were found to be important in their case focusing on trusted data-gathering systems. Lankton et al. [66] found that in terms of trusting a technical system, a system may be perceived as either more 'human-like' or 'system-like' which influences the trust assessments users undertake, where characteristics of ability, benevolence, and integrity vs. functionality, helpfulness, and reliability (or both) take prominence respectively. Trust in a virtual research environment as a system may therefore depend on how it is perceived by users, as it has both human-like and system-like functions, and the organisation or institution who hosts the virtual research environment may also be perceived as part of the system, having implications for the relevancy of a given trust model. In the case of the virtual research environment that we are studying there are strong long-standing institutional affiliations and scientific communities, with a history of creating and maintaining data repositories, all of which may be influential in trusting in the system.

As discussed above, trust in people, systems, and data are interconnected [52, 57, 59, 76] and cannot be "teased apart in practice" [57, p. 77]. However, we can begin to unpack some requirements relative to different actors for trust within virtual research environments. For some stakeholders, interpersonal trust is important in forming trust in data and trust in other users of the virtual research environment. This implies the mediator role of trust in technology may be most applicable. Yet for other stakeholders, trust beyond interpersonal relations is needed. Impersonal forms of trust [105], i.e. institutional trust, are interrelated with, and supportive of, interpersonal trust, often substituting and complementing each other [12, 63, 64, 106], forming the context within which interpersonal trust can develop [124]. For instance, those who belong to the same organisation or recognise another user as belonging to an organisation can infer initial trust cues based on this membership, including values and rules of professional conduct associated with it [5, 22, 38, 61, 70, 83, 84, 86, 103, 126]. However, in transdisciplinary research settings, we are no longer necessarily working *within* our community of practice, and the work may involve several individuals from different disciplines and backgrounds. When users are working beyond their epistemic community [116] there is often little or no familiarity with the data or with other communities in terms of standards and norms [23, 50, 110, 116, 117]. Trust is then placed *in the system* and the function of it, rather than specific individuals within, helping to navigate loose interpersonal connections [44, 62, 70, 73, 84, 94, 96, 116, 117]. The mediator and trustee models we have chosen include elements of institutional trust and the surrounding context of the model, 'contextual properties' [99] and 'institution-based trust' [81]. However, it is unclear with regards to the specific characteristics of the trustee (where both models differ) how these models apply to different stakeholders and to the different forms trust can take within a virtual research environment. Users' perceptions may also determine whether 'trust in systems' refers to virtual research environments or the wider institutions they are connected to, and whether trust in people also extends to those who work within virtual research environments and affiliated institutions, for example.

3 APPLYING TRUST MODELS

When coming to design a trustworthy socio-technical system, in this case a virtual research environment, it is clear that assessments, reasons, and willingness to place trust are differentiated amongst stakeholders and that, even when a model (or models) have been identified it remains unclear the approach to be taken and how one determines which model(s) to choose. In this section, we analyse these trust models in the context of a virtual research environment (Table 1), assessing the model fit by turning towards each model component in turn using both literature and our collective experiential knowledge working in this area. As the personality base of trust (propensity to trust and beliefs about others) is subjective and pecific to each trustor, we do not explicitly consider this component, but recognise that resulting trust is highly influenced by this, hence accounting for individualised responses to trust [21, 39, 69].

	Institutional Characteristics	**Trustee Characteristics**
Mediator Role (Riegelsberger et al.)	*Temporal Embeddedness (TD, TP, TS)*	*Ability (TD, TP, TS)*
	Social Embeddedness (TD, TP)	*Motivation - Benevolence (TP)*
	Institutional Embeddedness (TD, TP, TS)	*Motivation - Internalised Norms (TP, TS)*
Trustee Role (McKnight et al.)	*Situational Normality (TD, TS)*	*Functionality (TS)*
	Structural Assurance (TS)	*Helpfulness*
		Reliability (TP, TD, TS)

Key: TD (trust in data), TP (trust in people), TS (trust in systems)

Table 1. Application of trustee and mediator role models to the design of a transdisciplinary virtual research environment

3.1 Trustee Characteristics

We first consider the mediator role trustee characteristics before moving to the trustee role characteristics. *Mediator Role - Ability* is important for trust in people, trust in systems, and trust in data. Riegelsberger et al. [99] state that ability *can* be applied to trust in technology, as trust in both systems and people relates to expertise, predictability, credibility, accuracy, authenticity, and availability [99]. Within the umbrella of technological 'ability' they include: confidentiality, integrity (accuracy and reliability), authentication, non-repudiation, access control, and availability [98]. A virtual research environment may be trusted to preserve data reliably and accurately as submitted in the long-term [122]. This applies to trust in data itself, as authenticity, accuracy and credibility of data are important characteristics in determining whether to place trust [33, 35, 58, 104], and to those who created it as trust in data is derived in part from trust in the people who collected it. Trust in both data and the system also arises in part from the trained, expert staff who work within a repository [122]. The second characteristic, *Mediator Role - Motivation - Benevolence* is only typically related to forms of continuous interpersonal trust [99]. However, Riegelsberger et al. note that there can be another type of benevolence, such as from organisations towards consumers [99]. If we define a virtual research environment as connected to and built by a specific institution or organisation (as in the case of this paper), then benevolence could be appropriate concerning trust in systems, e.g., by signalling the ways in which they go above and beyond to help users with their concerns or expressing their commitments to trustworthy scientific research. Additionally, benevolence can also be connected to data producers, who act (in the most part) benevolently by providing their data to others and, importantly. spending significant time in ensuring that this data is usable, e.g., in terms of thorough documentation – thus a trustee is believed to want to good to the trustor [78], regardless of whether the trustor is known or unknown. The final trustee characteristic, *Mediator Role - Motivation - Internalised Norms* is important for trust in people, e.g., honesty and value congruence. Internalised norms could be applied to the virtual research environment as a system: responsiveness, openness, good will, principles, values, and standards are all connected to internalised norms [99]. For instance, Yoon [122] found that regardless of repository, trust was based on five broad components, of which one, 'organisational attributes' (including integrity and honesty, commitment to users and society, and values) is related to internalised norms. If the organisation or institution that a virtual research environment is connected to promotes these norms, or indeed a specific scientific discipline, then users may be able to ascertain internalised norms. Yoon [122] also notes that this is connected to trust in data, as repositories are trusted sources for data. Whilst data itself may not have internalised norms, these can be inferred from either the people or systems it comes from, e.g. honesty is used to determine credibility [21].

Turning towards the second trust model and the related trustee characteristics, *Trustee Role - Functionality* refers to trust in the system and it's capability, functionality, or features to complete a task. A key draw of virtual research environments is that they provide the potential to bring together different information, analysis methods, and ways of working, so functionality may be important for users to trust in the system. Following this, *Trustee Role - Helpfulness*, relates to the provision of adequate, effective, and responsive help to users, e.g., in terms of a help function. We don't see this as a feature of the system itself in potentially fostering trust for virtual research environment stakeholders by the system itself, *however*, we do see a potential source of helpfulness emanating from other users or staff to help foster trust in the data and models within a virtual research environment (a point we will return to in Section 3.3). Finally, the last trustee characteristic is *Trustee Role - Reliability*, that is continuous, reliable operation and predictable response. Consistency is important in terms of system downtime, but consistency or reliability can also be viewed differently in terms of longevity. Continuous, reliable operation is important over the long-term, it is very possible that to decide whether to place trust (even if a system is perceived to be trustworthy) may be impacted by the consideration of whether a system will be available in the future. As virtual research environments are not a long-standing feature of the research landscape, this is likely a key consideration. Reliability also relates to the people and data for the same reasons (Sect. 2.3), as consistently reliable and predictable data from a virtual research environment may be important to some users.

3.2 Institutional Characteristics

The surrounding institutional environment of a system is context-dependent. In our case, the virtual research environment we are designing is connected to existing institutions and organisations (universities and research funding bodies), and to a specific core group of scientific communities (though the system is open to a wider range of stakeholders to use). Trust can be developed from knowledge communities and their shared goals, values and identities [56, 116] and through reputation and recommendation from other community members [116, 122], but is reliant upon other users being cognizant of these affiliations in order to be able to use this information. Regarding the mediator role trust model, *Mediator Role - Temporal Embeddedness* relates to trust in the system and data, particularly in terms of longevity (as described by the 'reliability' characteristic, Sect. 3.1). Temporal embeddedness also relates to trust in people, if users are identifiable, it is likely that they want to maintain their reputation and so are encouraged to submit trustworthy data and to act accordingly within the system itself – this is particularly important given the 'barriers to entry' to belong to a scientific community, i.e., a prerequisite level of education and membership [99]. Trust in people also relates to social embeddedness (if users are members of these communities for the foreseeable future) and institutional embeddedness (if users are colleagues or members of the same community). *Mediator Role - Social Embeddedness* concerns reputation and recommendation, and relates to the trustee attributes of honesty, reliability, and dependability ('ability') [99]. As discussed in Section 2.3, this can be important with regards to trust in people and trust in data, formed through either reputation or recommendation. Even without the possibility of future direct interaction between a data producer and a data consumer, reputation is precious, being built over time through sustained effort, and can be 'lost' [84]. Finally, *Mediator Role - Institutional Embeddedness* may be important in forming trust in data, according to standards, policies, or rules of conduct, e.g., Dublin Core. If the system is connected to an institution or organisation, this can also help with forming trust in the system. Institutions can also signal personal attributes such as ability or honesty, and if membership is difficult to attain, it can signal information about the members' intrinsic properties or their professional qualifications [99].

Finally, we apply the institutional characteristics from the trustee role trust model to our design context. *Trustee Role - Technological Structural Assurance* would refer in this case to a belief that success is likely with our specific system because structural conditions such as guarantees, contracts, and support are in place with the general type of technology [81]. In this research setting, there are no guarantees or contracts as may be found in a commercial or organisational setting. However, support may be possible if the virtual research environment is affiliated with an institution or organisation. In this case, the user may perceive that, owing to this connection, there is either some type of guarantee (e.g., institutional association) or technical support available (e.g., from associated staff). This could potentially apply to data—as discussed above, inferences can potentially be made from a virtual research environment to data, i.e., policies guaranteeing quality or methods of recourse to query or correct data. Secondly, *Trustee Role - Technological Situational Normality* would be relevant if users have experience with virtual research environments (or similar) generally, they may therefore feel that success is likely in this instance with this specific virtual research environment. In our specific context, certain user groups do have a lot of experience with data repositories, but little experience with virtual research environments. It may be possible to capitalise on this, as similar communities and institutions are involved with both, thus helping users to construct a new situational normality in the presence of the introduction of new technology; however it is unlikely that across the board users will have this feeling of ease with the class of technologies generally. Situational normality could however apply to data: if users have ease and experience with data generally (e.g., data type, format, source, and topic), this may apply to specific data.

3.3 Further Characteristics

Trust in data, people, and systems are all interrelated and as we have shown, cannot be completely disentangled. We have found connections between components of trust models and our design of a virtual research environment (Table 1), and we have also noted some potential connections between model components and different types of trust but did not directly include these in the table.

3.3.1 Trustee Characteristics. Regarding trustee characteristics, *trust in data* relates directly to 'ability' from the mediator role model and 'reliability' from the trustee role model, but could, through connections with trust in people and trust in systems, also connect to 'benevolence', 'internalised norms', 'functionality', and 'helpfulness'. For instance, trust can be inferred from the benevolence and internalised norms of data providers. Data cannot itself be benevolent, but there are connections between the different trusts. Likewise, a system itself cannot be benevolent, but this trustee characteristic could apply if the system is perceived as connected to an institution or organisation. We felt that 'functionality' could potentially be related to trust in data but not directly connected, recognising that data could help users to complete a task and hence fall under the definition of functionality. We did not connect 'helpfulness' to any form of trust, owing to the specific definition of this trustee characteristic as 'a help function' by McKnight et al. [81]. However, we do see potential for this trustee characteristic, emanating from other users in the virtual research environment, which may help to foster trust in the system (e.g., recommendation of a virtual research environment) or in the data (e.g. to help with understanding). As would be expected given the rationale of the model, trust in systems aligned with the trustee role model characteristics of 'functionality' and 'reliability'. Likewise, regarding trust in people, we did find all the mediator role trust model characteristics to be connected, which is to be expected given the purpose of the model, i.e., trust in people mediated by systems.

3.3.2 Institutional Characteristics. We found the institutional characteristics of both trust models to be applicable to trusting in the system, but with mixed results for trust in people and trust in data. For instance structural assurance is applicable to virtual research environments, as it includes guarantees of preservation and sustainability by virtue of the system itself [121], and can relate to further guarantees at the institutional level (e.g. the virtual research environment we are involved with is connected to a research data centre, and thus connotes longevity and quality of data). This can potentially relate to trust in data in that it is retrieved from these systems, hence having assurances. We found weaker applicability in terms of situational normality, for the reasons outlined previously, but expect that this is dynamic, and may potentially change once users have more experience. Regarding both structural assurance and situational normality, Riegelsberger et al. [99] connect these to their contextual property of 'institutional embeddedness'. Perhaps surprisingly, we found that institutional embeddedness was applicable to all three forms of trust, in comparison to the institution-based trust characteristics of the trustee model. This is potentially because McKnight et al.'s [81] institutional characteristics are developed specifically for technology, relating them to the general class of technologies rather than the specific instance. This is suitable if we are thinking about a widespread class and type of technology, e.g., a word processor, but is slightly more challenging given that virtual research environments are not as widespread (Sect. 3.1).

At the start of this Section we described a scenario wherein even when we know the context in which we want to design a system and can identify potential trust models we are still a long way from knowing which path to follow – what do we do with this knowledge? How does one apply (or decide to apply) models? And, how do we implement this? In the following Section (Sect. 4) we discuss this analysis, including wider thoughts about this approach, as well as introducing the *alchemy* that we believe is required.

4 DISCUSSION

Our aim is to design a trustworthy socio-technical system, namely a virtual research environment in a transdisciplinary research setting. In consideration of the nature of transdisciplinary work, of trust, and of the context we are designing for, we realised that purely interpersonal models of trust are suitable in some instances, yet it was clear that there are no specific socio-technical trust models to account for both the wide range of users (known and unknown) and of trust in data and systems. From a range of potentially suitable models, we identified two models based on the roles a technology can take, a mediator role of trust between human actors through a system, and a trustee role, where trust is placed in the system itself. Drawing upon social science, philosophy, and computing literature we applied these models to our system and context, considering trust in data, models, and people. We found that no singular model is sufficiently comprehensive in respect to our design goal, but aspects of these models were applicable. We believe that "alchemy" characterises the course that needs to be undertaken — the processes of **transformation**, **creation**, and **combination** — are needed to creatively combine multiple trust models (or components thereof). We found that this characterisation is apt, allowing us to think about different dimensions of trust, to design for the multiple and intersecting trusts of stakeholders, and facilitating a view of the design of a virtual research environment through various angles. Yet *alchemy* also connotes some 'other' process, that ties in neatly with trust itself (Sect. 1). It is a blend of combination, transformation, and creation, *yet* there is also some quality that is not quite definable, an amalgamation of art and science, theory and practice that embraces nuance and complexity.

4.1 The Alchemy of Combination

As we have shown, there are many models to choose from and many ways in which trust can be modelled. Whilst we can identify which trustee characteristics are applicable to specific types of trust (Sect. 3), "choosing which trust in technology constructs to use may not always be clear-cut" [66, p. 881]. *Trust contains multitudes*: it is multi-faceted and multi-dimensional, theorised in terms of different bases, levels, and types of trust which are interconnected and interrelated [39, 82, 103]. Stakeholders develop trust through complex and individualised processes, therefore any one of these trustee characteristics may not by itself foster trust or allow a user to place or refuse trust. As these are tacit processes, we cannot say whether a user specifically delineates between these model components, e.g., selecting a system because it exhibits ability, or if they simply just experience trust [54]. Any model, if used as a base to design, should be reflective of these considerations. Given this, how do we reconstruct these pieces of models into something that is logically and conceptually consistent, and that helps us to model trust in our specific context?

A virtual research environment can be perceived as a trustee or a mediator (or both) as virtual research environments can potentially be the objects of trust themselves; contain data and models which can also be objects of trust; and can, when designed for, enable communication between users. Upon reflection of the application represented within this paper, we believe that models *should* be combined, but that greater consideration is required when doing so — deciding which role a technology will take can impact on design choices and trust models [66, 107] — so too can the combination of these roles. Is this a case of taking multiple model components and combining them into one model, or is a greater level of finesse (matching the intricacy and reality of trust) required? How does one creatively adapt existing trust models to successfully design? We argue that a *creative alchemy across models* is required. Even though both models' trustee characteristics have been linked to the characteristics of the ABI model [78] (Sect. 2), we found that these apply very differently and therefore, both characteristics e.g. 'ability' and 'functionality', will be required and can be framed as one singular trustee characteristic, but must be differentiated in terms of trust in people, a system, or in data. The mediator role model allowed us to subsume components from the trustee role model, e.g., structural assurance and situational normality into institutional embeddedness. Yet, the model alone does not contain all the components we feel resemble the design of a virtual research environment in transdisciplinary research. We have, as part of further work, begun to consider how these models work empirically, considering how a combined model accounts for different users and different trusts, and further undiscovered components. Thus far, we have found that this is a fruitful endeavour but to enact any model into design requires further transformation.

4.2 The Alchemy of Transformation

Through this design process we have found that even when a model or models have been selected and are applicable to our system, how does one go from selecting a model or models to translating those into design? Models are useful tools for explaining and understanding phenomena, *especially* with trust, which can be an ostensibly complex concept at times. However, all models are "necessarily imperfect representations of the rich phenomenon humans understand as trust" [76, p. 3]. Given this, how do we translate a model into features, without simply producing a list of requirements or guidelines to tick? Both models' authors [81, 99] point to specific technological features that can be used to 'signal' characteristics. As we have highlighted, there are multiple stakeholders who use multiple modes and means to trust and so we argue that alchemy is necessary for the features of a system too, *especially* given that each discipline and project is different, and has different norms and needs, flexibility and user-definition will also be a necessity [15, 74, 95, 120].

Models, we found, do not take account of users and their practice, and can become unwieldy when we try to slot these into a neat and concise model-shape.

We have begun to think about this next stage of work. We do not view models as lacking utility, they have been useful in this work, analytically guiding us to consider trust from multiple angles and through various perspectives. However, we do dispute the use of models as the end point of any trustworthy design work. The metaphor of alchemy has allowed us to develop and advance our thinking about trust, we cannot simply take a model 'off the shelf' and insert this into a given context nor can we simply import features and expect a beneficial outcome in terms of trustworthy systems. We argue that the same is true of features. As an approach, alchemy acts as a useful bridge between models – which can often feel prescriptive and rigid – and design – which is flexible and open-ended. There is something distinctly two-dimensional about models. What we long for is a more tactile representation of trust, to pick them up, deconstruct them, mould them into a new shape according to not only the context but the different trusts for different stakeholders within this context. Whilst we have not considered further transformation within our paper, this is one line of future work we hope to explore, investigating the potential of patterns [59] and affordances [66, 114] alongside and in combination *with models* as a complete reflection of an alchemistic approach to designing for trust.

4.3 The Alchemy of Creation

We must also consider what these models return when translated to a specific context. We found that in combination these models were suited to a *socio-technical* system, particularly because of the mediator role trust model of technology. However whilst both models use social-psychological approaches to trust [81, 99] — meaning that characteristics are perceptive not objective [81], that the perfect information to make a rational decision is unattainable [12, 44, 70, 110] and that trust involves a mix of both emotion and cognition and is partly non-rational [19, 44, 65, 68, 70, 72, 81, 85, 88, 119] — this does not relay to the end model. Whilst elements of affective trust are included, cognitive trust is the most prevalent. The focus on intelligility and explainability within recent trust literature (particularly in AI) point towards certain cognitive aspects of trust models, but trust is not *purely* cognitive. We are therefore interested in exploring how we can model affective trust more fruitfully. Trust in data, as we have shown, is not solely about the characteristics of the data and understanding the data through supplementary information, trust in data also involves trust in people, e.g., where a full consideration or understanding of available information may be not be required if trust in the reputation of the data producer. Along these lines, we will also consider missing components from these models when combined. For instance, transparency has been added to the ABI model in other adaptations [93], and Yakel et al. [121] mention transparency as one of their four indicators of trust in data repositories. Thus, we see this as a potential avenue for future investigation – particularly amongst different stakeholders and their conceptions of trust. In a similar vein, we found that trust in data is mediated by trust in people and trust in systems, but that there are model components where trust is placed in data directly. Therefore we will also seek to include models of trust in data, following the process described within this paper in an attempt to further advance our thinking and successfully achieve our design goal.

4.4 The Creative Act of Alchemy

Finally, we turn to the approach we have presented in this paper. The models that we have analysed are applied to a specific version of a virtual research environment. A key point we have sought to emphasise in our paper is that, precisely because trust is specific and dynamic, designers need to creatively apply trust models to their *own* contexts. We found that the mediator role trust model by Riegelsberger et al. [99], was much easier to apply to our context in terms of applying institutional and trustee characteristics but this may not be the case for other systems. As discussed above, we found that the institutional (contextual) properties of the mediator role model [99, Fig. 5, p. 399] were easier to apply than the trustee model [81, Fig. 2, p. 12], owing to the definition of technological structural assurance and technological situational normality [81], because virtual research environments are not as widespread as other forms of technology to which the model could be applied. Additionally, if there was not such a strong institutional context in which the system sits, the results — and hence the resulting model — would be different. We found however, that despite this strength, these institutional characteristics of the trustee model privilege certain types of stakeholders. For instance, temporal and social embeddedness applies to trustors and trustees that are expected to be members of these communities for the foreseeable future [99]. This therefore applies to core groups, such as specific scientific disciplines in our context, but may not necessarily help a data producer to trust that their data is being used correctly by an unidentifiable person who is not part of said community, or for an unconnected data user to identify institutional signals. In sum, we believe that the mediator model speaks to the design of socio-technical much better than the trustee role, if we were comparing the two and deciding which model to follow. *However*, following the alchemic approach offered here, there does not have to be a choice between two models, and it is feasible — if compatible and coherent — to combine models to fully reflect a design context.

We encourage designers to become alchemists of trust to enable a new way of thinking and of designing. This approach has been freeing, we found that it was challenging to work with models as — even though models are necessarily imperfect and general representations of reality and we would not expect to find a perfect model already in existence — we could not see a single model that could provide a structure for our theoretical and empirical undertakings when designing a trustworthy socio-technical system. Following this process has enabled us to experiment with models in a way that we have not found within the literature, where trust models are often treated as ground truth and proliferate in much the same form with minor adaptations in different contexts. We therefore borrow from data science, wherein ensemble models are often created, and apply this to a social science-based information system design process. We believe that our approach is suitable to the goal of design and this approach is suitable to other system design, allowing system designers to question and think about the challenges found in system design when it pertains to trust. Whilst many of the trust models and adaptations we reviewed used statistical methods (e.g., [66, 81, 107]), we have found this conceptual approach (similar to [99]) fruitful, and one which we hope to empirically test in the future.

5 CONCLUSION

Well-placed trust is essential for ensuring the success of transdisciplinary research and the ability to address complex and wide-ranging societal challenges: interpersonal co-located trust is extensively modelled within trust literature, yet virtual trust between users, and trust in data and in systems are also of importance in socio-technical design. Addressing these different trusts in design is complicated, trust is slippery and is challenging to define and design for — even for those well-versed in trust literature, the different types, bases, levels, and models of trust are admittedly confusing. Models of trust are useful to understand and explain such complex phenomena, yet there are few models one can utilise. Designers, we argue, must face the challenge of trust head on, but there is often no clear route one can take.

We have proposed *alchemy* as an apt metaphor of the process involved in successfully designing for trust, wherein designers can become *alchemists of trust*, transforming, creating, and combining models tailored to their specific context, and creatively considering both stakeholders and their multiple trusts. Within this paper we have provided some illumination and clarity by consolidating relevant trust literature pertaining to socio-technical information systems and have demonstrated an approach that can account for the complexities and dimensions of trust [114]. This approach speaks to the concept of trust itself — often considered *mythical* [88] and *elusive* [14] — there is great deal of subtle variance and nuance within 'trust' that we don't have a good language for describing. The use of 'alchemy' has facilitated a much richer exploration of the nature of trust models in a design context and has advanced our thinking greatly.

In future work, we aim to build upon this paper, by producing a fully developed model, combining this with other design theories, in particular looking towards affordances [114], and transforming beyond flat, two-dimensional representations of trust to fully account for multiple stakeholders and multiple trusts. We plan to empirically test the outcomes of this to inform the design of a virtual research environment, and investigate the the ways in which models can be useful to the design process, and sufficiently capture the reality of trust for various stakeholders. We hope that our work can enable system designers to creatively engage with the trust literature, to identify potential models rather than relying upon a singular model, and to have the confidence to combine them. In this way, as alchemists of trust, designers can successfully attend to present, known users and future, unknown users.

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