Design Science

Research through co-design

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Abstract

Research Through Design (RTD) needs to reconsider the meaning of "designing" in the research process of "through design." We propose Research Through Co-design (RTC) as a new application of Control System Theory (CST) that includes a research problem assigned to a co-design process in RTD. It embeds the participatory paradigm through collaborative design practice and makes the research a collaborative process for learning from all the participants. To sustain the RTC theory, we present a cognitive model of RTC. It is a "model for" – rather than a "model of" – describing how the co-design, as a neural network process, works through its nodes' collaboration to find co-designed solutions and the research answer. Diversity increases as non-experts and non-designers with different backgrounds participate. This is valuable for the RTC learning system. The discussions highlight the possibility of considering (i) the RTC model as useful for describing a robust RTD process through CST; (ii) RTC as a cognitive model for explaining the value of co-design in research processes; and (iii) RTC as a strategy for applying the participative paradigm in formal research. Finally, new insights and implications are highlighted, including using RTC as a predictive tool through artificial intelligence.

Keywords: Research Through Design, Research Through Co-design, Co-design, Research-oriented co-design, Control System Theory, Co-creation of knowledge

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1. Introduction

This study tackles issues that come both from the Research Through Design (RTD) and co-design realms. Specifically, our interest is in understanding how it is possible to consider co-design within the knowledge related to RTD. This is because RTD is a contemporary challenge for design research. However, in this realm, co-design is poorly discussed and addressed as a crucial variable that may interfere with the multiple aspects of an RTD process. Because design is at the core of the RTD ontology, the typology of design practice may assume relevance in determining the validity of the RTD process. This is the reason why we underline that "co-design" needs specific attention as a peculiar design process that determines not only a variant of RTD but a perspective that needs a new reflection. Co-design is generally interpreted as designerly collaborations and as a practice to involve people, but it is still not considered a formal research practice, with a formal general model that produces new academic knowledge. We aim to advance this aspect by matching co-design with RTD, through the Control System Theory (CST).

Finally, this article also addresses the role of non-designers in co-design practices embedded in research processes. In this context, non-designers represent a variable that is impossible to tackle with predictable aspects. Non-designers, even if recognised as important for de-structuring and opening the creative design process, may also represent a risk for reaching the design (or research) objectives with innovative results. On the contrary, we provide theoretical reflections that potentially demonstrate how diversity in co-design embedded in RTD processes, is a resource to obtain a relevant research answer. To address these aspects, after the literature review, we propose a focus on Research Through Co-Design (RTC) as a concept that may clarify how to match the aforementioned issues. Indeed, based on RTD, CST and co-design, this article discusses RTC as a research strategy. Prior studies (Busciantella-Ricci & Scataglini 2020c) examined the possibility of conceptualising the RTC theory by outlining its underpinnings. On the one hand, there is a lack of clarity on the practical application models in RTD literature. On the other hand, the co-design peculiarities are rarely studied as variables that may change the concept of designing within RTD. In design thinking or research procedures that employ design as a strategy, co-design is becoming increasingly important. Therefore, a description of this position inside RTD, what adjustments have been made, and how they have affected RTD would be beneficial. Consequently, we suggest RTC that aligns with (i) the requirements of the RTD approach, (ii) the co-design as a participation strategy and (iii) a rigorous model to merge these aspects in a unique framework. This study includes an introduction of the main literature on RTD, co-design and RTC, as well as improvements in the RTC model and their implications for design research processes. Finally, this article considers the possibility of developing an RTC model that allows practitioners and researchers to design, develop, predict and compute the variables of a research process that must use co-design as the primary strategy for participation, co-creation and democracy in innovation.

1.1. RTD: an introduction

RTD is one of the types (Glanville 2005) or categories (Frayling 1993) of design research. As Glanville (2005) suggests, RTD is "research that recognises its source in design, and which uses the insights and understandings of design in its pursuit." Firstly, Frayling (1993) introduces the differences between research about, for and through design. Archer (1995) proposes notions such as research about practice, research for the purposes of practitioner activity or research through practitioner activity by also indirectly underling a difference between a professional and a researcher. According to Archer's perspective, the "research through practitioner" activity, where the medium of that practice is relevant for the systematic inquiry whose goal is "communicable knowledge," can be compared with action research. Specifically, through Archer's thinking, this kind of research mediated through the practitioner activity "can count as research if, and only if, it accords with the criteria of research. It must be knowledge-directed, systematically conducted, and unambiguously expressed. Its data and methods must be transparent and its knowledge outcome transmissible. But like all Action Research, research through practitioner action must be recognised as very probably non-objective and almost certainly situation-specific" (Archer 1995). Often, the possibility of generalising RTD experiences, as well as providing rigour and academic credibility, has been the

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focus of the design research studies. In the last decades, several authors have widely amplified the RTD discourse (e.g. Frayling 1993; Glanville 2005; Findeli *et al.* 2008; Chow 2010; Jonas 2015) also taking into consideration the importance of combining research "about" and "for" design in RTD to make it relevant and rigorous (Findeli *et al.* 2008; Jonas 2014, 2015). Indeed, by contrasting Frayling's (1993) framework, Findeli *et al.* (2008) highlight that RTD "could be defined as a kind of research about design [more] relevant for design, or as a kind of research for design that produces original knowledge with as rigorous [and demanding] standards as research about design." This position leads Findeli to call this approach "project-grounded research" which is more significant for contributing to creating design knowledge, improving design practice and framing consequences for design education. On a similar pathway, Jonas (2014) refers to RTD as research "in the medium of design, guided by the design process, aiming at transferable knowledge and innovation according to various internally determined criteria." Effectively, RTD uses the design thinking process as the main medium to gain knowledge that is both related and relevant for the design knowledge and for the knowledge of those fields that benefit from the design within the RTD process. We mainly create this vision by interpreting the Jonas perspective of RTD (Jonas 2007, 2014, 2015). Also, in this discourse, Zimmerman, Stolterman & Forlizzi (2010) describe RTD as "the process of iteratively designing artifacts as a creative way of investigating what a potential future might be (…)" an approach that "allows designers to do what they do naturally (to design), and to create a stepping-stone to theory generation."

In addition, during the last decade, the Research Through Design Biennial Conference fuelled the debate starting from its foundation in 2013 and as a dissemination platform (Durrant *et al.* 2017). According to Durrant *et al.* (2015), this experience allows us to reflect on the knowledge production about design research that can be also generated by the interaction between people and artefacts as part of the conference experience. This aspect emphasises the relevance, for some authors, of the artefacts in producing knowledge through RTD, while Jonas (2015) underlines the importance of considering the design process as a unique epistemological medium for gaining knowledge.

From a wide perspective, when design assumes a central role in the research objectives, that process can be defined as RTD. For instance, Sevaldson (2010) synthesises RTD can be defined as any research where "the design practice is central in generating knowledge." This suggests considering and understanding what we mean by the central role of the design practice. Usually, it is intended as the central role of the practice made by practitioners in design that, if supported by relevant and robust reflections, can produce research material (Archer 1995; Cross 1999; Swann 2002). This may also open interpretations of the term "through" to understand the RTD practice (as proposed by Redström 2021) or underline the inseparability of design components (i.e. process, designers/researchers, objects) (Isley & Rider 2018). Similarly, Dixon (2019, 2020) connects RTD with Dewey's pragmatist framework which also helps to frame the relevance of the (design) practice for design research.

In general terms, according to Godin & Zahedi (2014), RTD "is very similar, in appearance, to a regular design project," it is not predictable, and knowledge and understanding are the main goals rather than the artefacts. However, Herriott (2019) underlines that, despite RTD seems to embed the idea of a "designerly way of knowing" (Cross 1982, 2001), it is not demonstrable the designer's unique to

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gain knowledge and the fact that knowledge resides in process and artefact (Herriott 2023). These aspects may also influence ways future designers, design researchers, designers-researchers or simply researchers can decide to address or not the RTD approach, as well as the way we rethink design education (e.g. Galdon & Hall 2022).

In the meantime, despite the multiple variants, RTD is also explored in several disciplines and fields related to design (e.g. Lenzholzer, Duchhart & Koh 2013; Maher *et al.* 2018; Groeneveld *et al.* 2019; Shroyer & Turns 2021; Bofylatos 2022; Cortesão & Lenzholzer 2022) with multiple interpretations also (e.g. Suberi 2022) by evidencing an interest in finding formal models and frameworks for its application. RTD essentially produces knowledge for a discipline (not necessarily related to design) through the application of design knowledge of the contemporary design culture (Jonas 2015). By "design culture" we mean the cultural background that designers (or non-designers) should elaborate on and use for designing (Julier 2006, 2013; Manzini 2015, 2016). The debate on the nature of RTD spills over into various aspects that depend on how design culture is formed and interpreted. The RTD variety is also understandable by reading the multiple instruments and models that are possible to find in RTD literature, embodying the diverse perspectives on this concept.

1.1.1. RTD instruments and models

In the following paragraphs, we also focus on the numerous perspectives and theoretical instruments the research in RTD has produced over the last decades. For instance, among the different perspectives in interpreting RTD and similar terminologies, it is worth mentioning the work offered by Chow (2010) that compares three research models based on the belief that "designing is a way of knowing and this way of knowing ought to be used in and for research." They are the Project-Grounded Research (PGR) (Findeli *et al.* 2008), the Practice-Led Research (PLR) (Rust, Mottram & Till 2007) and RTD based on Glanville (1999) and Jonas (2007) perspective. Chow (2010) concludes that RTD "is the most theoretically elaborate and most ambitious proposal among the three research models." However, several perspectives emerge to enrich the debate to develop RTD between research and design. Indeed, Stappers (2007) underlines that, rather than giving academic credibility with research to designers, we should take advantage of some design skills they have that are valuable ingredients for research, including skills such as (i) creating prototypes, (ii) fostering design research through studios and (iii) giving results through publications. Gaver (2012) suggests considering discursivity and elaboration rather than only standardisation and convergence as models for RTD development. Jonas (2015) writes that "RTD has the potential to act as the epistemological paradigm for transdisciplinary studies and transformation design" and in discussing RTD visualised the idea of this model of inquiry. It means that "RTD cannot exist as an isolated concept, but that it has to integrate the other modes of inquiry. Scientific input (about, for) is indispensable, but the nature of the design phenomena does not allow the reduction of design research to (applied) scientific research. On the contrary: scientific research has to be embedded in designerly models of inquiry. There are the all-embracing subject matters of aesthetics/products – logic/process – ethics/people, and the essential distinguishing purposes of understanding

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design-relevant phenomena, of improving the design process, and of improving the human condition. These purposes can be related to the epistemological attitudes of research about design, for design, and through design" (Jonas 2015). Markussen (2017) also proposes three forms of theory construction in RTD; that is (i) "extending theories" where the design process expands kernel theories; (ii) "scaffolding theories" where theory is constructed out of separated theories and (iii) "blending theories" where the design work fuses more concepts to produce a new understanding.

The richness of the perspectives also comes from different backgrounds. For instance, Stappers & Giaccardi (2017) identify a map of RTD projects and articles that underline four "pockets of energy" from different fields and geographical collocations. The map underlines those contributions coming from the art and design community (UK and Scandinavia), technical universities and design academies (Netherlands) and the human–computer interaction community (US). In addition, Stappers & Giaccardi (2017) collected eleven examples of how different authors label RTD and research in design. Indeed, other similar meanings have been introduced such as "practice-based research" (PBR) (Candy 2006; Biggs & Büchler 2007; Mäkelä & Routarinne 2007), "constructive design research" (Koskinen *et al.* 2011), "programmatic design research" (Löwgren, Svarrer Larsen & Hobye 2013; Bang & Eriksen 2014), "empirical research through design" (Keyson & Bruns 2009) just to name a few relevant for this article. Often differences are related to the role assumed by the artefact or the design process. For instance, according to Menichinelli (2020), the difference between RTD and PBR is that the first has the goal of exploring a phenomenon with an artefact as a side effect, while the second has the artefact as the goal and insight as a spin-off.

Over the years, design researchers also stressed that RTD has to find ways of approaching research qualities such as "reliability, repeatability, and validity through ways that are trustworthy while true to the approach" (Zimmerman *et al.* 2010). In this direction, Prochner & Godin (2022) propose a framework for quality indicators of RTD projects made by categories (i.e. Traceability, Interconnectivity, Applicability, Impartiality, Reasonableness) and specific indicators (i.e. Replicability, Recoverability and Transparency, Internal validity, Credibility, Contextualisation, External validity, Transferability, Impact, Objectivity, Confirmability, Contextualisation in theory and research, Reliability, Dependability, Soundness of research methods and research norms).

In terms of process, Zimmerman & Forlizzi (2008) underline that RTD is an approach that "employs methods and processes from design practice" and "design researchers follow a typical design process" that can be described in six phases, that is Define, Discover, Synthesize, Generate, Refine, Reflect. In this perspective, the artefact serves as a "specific instantiation of a model – a theory – linking the current state to the proposed, preferred state" (Zimmerman & Forlizzi 2008). In terms of dynamics, Basballe & Halskov (2012) underline that RTD has three types: (i) "Coupling" that establishes frameworks and constraints by uniting design and research interests; (ii) "Interweaving" in which "one activity or material informs both design and research interests" and (iii) "Decoupling" that "modifies the focus, by turning either design or research interests into the salient focus of the process."

In terms of models that may inspire the embedding of co-design in RTD, Stapleton (2005) presents the RADDAR methodology to understand how the

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research and theory area can create reflection and differences (and vice versa) with the design and practice area. The RADDAR methodology creates a dialectic among the two areas. This dialectic is the core of the discussion in RTD and, even if Stapleton (2005) focussed on game design practices, this methodology may inspire reflections by also thinking about all those design activities that recall the concept of "practice" for finding research answers. Also, one of the most quoted in design literature is the contribution offered by Zimmerman, Forlizzi & Evenson (2007) that essentially proposes an RTD model for Interaction Design Researchers (IDR). Through this model, it is visualised that the IDRs may integrate knowledge from several fields such as engineering, anthropology and behavioural science to concretely frame problems through a process of ideating, iterating and critiquing potential solutions, until obtaining the preferred state, and a series of artefacts, and also models, prototypes, products and documentation of the design process. In this model, it is still possible to feel a conceptual divide between those who intervene in HCI as researchers, and those as practitioners. Instead, in many other contributions this diversity is even discussed with overlapping systems that justify the nature of RTD.

In parallel, Jonas (2007) introduces a generic hypercyclic design process model that can represent a basic design process for RTD and it can be operationalised linearly (Chow & Jonas 2008). The hypercycle model of the design process contributes to sustaining the designerly production of knowledge by providing a cybernetic foundation for design, which also "serves as a framework for design and design research practice" (Jonas 2007). Jonas's (2014, 2015) discourse underlines RTD as a cybernetic mode of inquiry (Jonas 2014). We follow this part of the RTD discourse as a foundation for this article. Indeed, Jonas (2015), by referring to Archer (1995), Owen's model (Owen 1998) and Findeli's (Findeli *et al.* 2008) perspective, insists that RTD is "an embodied/situated/intentional observer inside a design/inquiring system, generating knowledge and change through active participation in the design/inquiring process" where design is seen as a "projective process, human-centered process, innovation process, emancipatory process, political/social process" (Jonas 2015).

Indeed, Jonas takes distances from "Frayling's understanding of the artifacts," follows Findeli & Bousbaci's (2005) perspective and affirms that "RTD is not primarily about conceiving artifacts/products as carriers or representation of knowledge, but about conceiving the design process as a unique epistemological and methodological medium/device for knowledge generation, different from other disciplines' instruments" (Jonas 2015). This is a fundamental perspective for this article. It lets us think about differences in designing processes for using design as an epistemological process and how they impact RTD. Therefore, there should be a substantial difference between considering design and co-design in the RTD process. This is also why we suggest considering co-design as different in RTD through this article.

Jonas' (2015) visualisation of RTD is one of the most structured among the models offered in the literature. We adopted this model as our starting point for reflecting on how to provide an application model that embeds the ontological and epistemological factors we have discussed so far. This article mainly follows the position offered by Jonas's discussion on RTD and design as research. In these instances, we found the foundations for the openness of similar issues in introducing co-design within the ontological and epistemological issues of RTD.

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To continue the overview, Faste & Faste (2012) underline that all research is a subset of design practice at large and propose a 2 × 2 matrix for describing known categories of design research. In this framework, RTD is described as "embedded design research" which is "design activity that operates as research" and "the knowledge generated is contained in the cognitive processes and artifacts of the design activity performed" (Faste & Faste 2012). Bang & Eriksen (2014) propose a diagram that interprets how different experiments in RTD interplay with research questions about the research program framed within and with the answer as a response to the overall challenges or matters of concern. Stappers & Giaccardi (2017) visualise the designerly ways of contributing to research and the designerly ways of doing research. It helps to understand how the design activities play a formative role in the generation of knowledge. Rodríguez Ramírez (2017) suggests a criteria-based design research model targeted to conduct practice-based research such as RTD. The stages of the model are (i) situating the research within the body of knowledge of the discipline (e.g. literature reviewing); (ii) free experimenting around the topic of research through making (e.g. sketching, rapid prototyping); (iii) designing to address and fulfil the developed criteria (it renders the designing a systematic enquiry) and (iv) assessing the final designs through the criteria by also describing the design and its explicit contribution to knowledge.

Also, Herriott (2019) describes a simplified RTD process with the main steps of (i) defining the state of the art and the research question, (ii) creating the object, (iii) analysing qualitative and quantitative data produced by the object and (iv) formulating a new theory or modification of the theory. However, Herriott (2019) claims RTD is analogous to experimental research/science and "unless tacit knowledge is elevated to the same level as explicit or communicable knowledge, the idea that there is a designerly way of knowing is either an unsupported or a weak claim" (Herriott 2019).

In parallel, Krogh & Koskinen (2020) explore "ways of drifting" in "constructive design research" and discuss the Knowledge-Relevance (K-R) Model. It is a model that presents the design experiments at the core and it "enables researchers to continuously map and re-map their research activities as a conversation between hypothesis construction, experimentation and evaluation, assessed in relation to both knowledge theory and impact, in the ambition of being relevant and producing knowledge" (Krogh & Koskinen 2020).

Finally, it is not new that discourses around RTD and practice-based research activities refer to concepts such as the "reflection-in-action" (Schön 1983), the action research model (Archer 1995; Swann 2002) and the related comparisons with RTD (Stewart 2014). We do not introduce a general action research model here because we will introduce the "participatory action research" (PAR) model by discussing RTC in the next paragraphs.

As described so far, the literature offers several general and not homogeneous perspectives and models of RTD that do not necessarily describe the same theoretical, conceptual and practical aspects for discussing and applying RTD. This is partially what Boon *et al.* (2020) describe as "diversity" in RTD.

1.1.2. Considerations for the purpose of RTC

In search of a reference model for building an RTC foundation, literature seems to provide the basis for the conceptual framework. At the same time, the literature

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does not provide a homogeneous perspective for RTD, as well as a unique model to easily make RTD applicable in several design research activities through principles, methods, processes and tools to be systematically applied. Several authors propose their own model and perspective in addressing RTD both from a theoretical and practical point of view, and the number of coined terms around the meanings of RTD makes evidence of this aspect. On the one hand, the need to discuss the validity and rigour of this kind of design research created the need for searching theoretical foundations and philosophical aspects to base on the practice and the development of RTD. On the other hand, it is possible to observe distinct approaches to RTD, that is (i) considering the tangible "object" as the medium for understanding new knowledge, and (ii) using the values, the attitudes and the design processes, as the epistemological medium for gaining knowledge outside the very concept of "artefact." In any case, there is no consensus on (i) how to relate research questions with the design questions in an RTD process, (ii) how to design stages for applying RTD and (iii) how to consider the multiverse and wide possibilities offered by design in terms of approaches, methods and tools, including those related to co-design. The perspective that design methods are RTD methods is promising but not convincing, especially if, with those instruments, we pretend to gain knowledge about complex problems or global issues, through participative design processes, and with non-designers. At the same time, it is not clear from the literature why and how co-designing rather than designing should or should not be considered the same in an RTD process. All these aspects represent gaps or unclear topics we try to discuss by introducing co-design as one of the most challenging aspects of RTD. Our purpose is not to standard RTD through co-design but to enrich the debate by focussing on co-design as a useful explorative and speculative resource for diversifying the attitudes in the contemporary design culture.

1.2. Co-design: an overview

The reason why we focus on co-design as the main determinant of the RTC system is the shift we are observing from "designing" to systematic "co-designing." This can be more understandable not only for ethical and philosophical reasons but also for practical reasons. As Manzini (2014) wrote, in the world of networks "all design is co-design." Nowadays, we cannot escape from interacting in a (co-)design process. "Being influenced by different actors, every design process is, de-facto, a co-design activity" (Manzini 2014). Indeed, co-design is based on several kinds of conversations which themselves are analogous processes of designing (Pangaro 2008 in Jachna 2019); therefore, once again, "there is thus no designing that is not co-designing" (Jachna 2019). However, the "co" opens interesting perspectives about designing. Even if collaboration, cooperation, connection and coordination cannot be considered synonymous (Kozar 2010), in terms of collective design all four terms "are possible expressions of co-design practices, distinguished on the basis of how strongly they focus on shared goals and working practices" (Zamenopoulos & Alexiou 2020). In this article, we talk about co-design only concerning the term collaboration, with consideration to people who work together towards a common interest, project and goal (Zamenopoulos & Alexiou 2018, 2020). At the same time, we recognise co-design as a process that follows the principles of participatory design. In this view, based on democratic principles, co-design is manifested only if people actively participate in the whole design

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process, otherwise if people with contextual knowledge and lived experience "are not actively involved in the design process, but emphasis is put on their views and experiences, the process could be described as user-centred or human-centred design" (Blomkamp 2018). Indeed, collaboration and collaborative (design) approaches change how we research, what we research and who researches (Sanders & Stappers 2008). From this perspective, we can also understand one of the main issues in co-design that is related to the roles and relationships the different people assume in the participatory process of designing. This also recalls the connection between design and participation where according to Lee (2008) is possible to map three (designers) roles, i.e. (i) "Design Developers" that work with the design community "to transform design processes for participation"; (ii) "Design Facilitators" that design with people "to transfer design knowledge to emancipate people to improve their lives" and (iii) "Design Generators" that collaborate with professionals "to explore design thinking to different implications."

By assuming participatory design as the main comprehensive term for co-design, we understand that participatory design projects are always grappling with the understanding of how to involve people, with which means and tools, and how to make the design process democratic and inclusive for everybody – including non-designers. This is the reason why there is a continuous methodological evolution in participatory design, also through processes and tools that define a new way of conducting co-design (Robertson & Simonsen 2012). This also takes into consideration that co-design is a disagreement space based on possible language misalignment. It is a process where different people interact by converging (or not) on common results emerging from different perspectives and languages. These results "can be particularly interesting, resilient and rich in cultural qualities" (Manzini 2014). At the same time, co-design is a space for conflict, that, through the values of participatory design we can define as constructive and creative conflict. Despite these complexities, contemporary society is pushing for using creativity and collaborative practices as collective resources for sharing knowledge, activating co-creation processes and provoking systems changes (Jones 2018; Eckhardt *et al.* 2021). Indeed, co-design in systemic design processes is a synonym for "co-creation" for addressing social transformation with system stakeholders (Jones 2018). In general terms, co-design is a way to apply collective creativity in the whole span of a design process (Sanders & Stappers 2008). It is a "mechanism for empowering people, namely a mechanism for taking control over their own futures by developing their own ideas, knowledge and skills" (Zamenopoulos & Alexiou 2018). Perhaps, this is the reason why emerging design approaches such as Transition Design (Irwin 2015), Design for social innovation (Manzini 2015) and Design for Policy (Bason 2016) mostly recognise design as, basically, a collaborative design process. Literature often addresses the co-design discourse through its role or application within social innovation practices (Manzini 2015), participatory and democratic processes (Ehn 1993), knowledge co-creation processes (Garcia *et al.* 2014), as well as for citizen engagement and public policies making (Siodmok 2016; Blomkamp 2018; Deserti, Rizzo & Smallman 2020). Canonically, co-design is a participatory process where people learn from each other (Ehn 1993). For the purpose and perspective of this article, co-design is recognised as an activity that "produces new knowledge as people develop and experiment with (new) ideas" (Zamenopoulos & Alexiou 2018). In

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addition, we also assume that co-designing is not easy, it is a "complex, contradictory, antagonistic process in which different stakeholders, design experts included, participate in different ways, bring their specific skills and their culture" (Manzini 2014). These issues are also why user tests or marginal people's participation (e.g. only interviews) is often confused or promoted as co-design processes. However, co-design "contributes to democratisation and empowerment because it can facilitate the closing of the gap between people who have the power to shape important aspects of their life, such as health, welfare or built environment, and those who do not" (Zamenopoulos & Alexiou 2018).

In the co-design discourse, the co-designer role is a matter of discussion. One of the most cited papers about co-design describes a basic co-design process as made by the role of designers, researchers and users (Sanders & Stappers 2008); essentially a process among experts in design and people that participate to produce knowledge through the co-design process. However, the role of the expert co-designers recalls the role of designers in the participatory ecosystem and in building collective design intelligence (Manzini 2019); and it is not solved yet. However, labels such as experts and non-experts, trained or not trained in (co-) design (e.g. Manzini 2015, 2019; Meyer & Norman 2020) are a concern under discussion. It also evolves as design skills are demanded in different societal contexts. For instance, in bottom-up social innovation participatory processes, the role of the expert designer is closer to a non-design-expert who acts as a designer (Manzini & Rizzo 2011). Indeed, demarking boundaries of experience and training, as well as skills in co-design processes is difficult and probably useless (Busciantella-Ricci & Scataglini 2020c) and adds no real value as in the case of "design demarcation" (Whiting 2021). However, for understanding how designers, people or design experts (as we want to call them) roles in co-design, the proposal of the Collaborative Design Framework (Meroni, Selloni & Rossi 2018) may help. It works as a guide for helping infrastructure collaboration in those the authors defined as "massive" processes (Meroni *et al.* 2018). It can be also useful to understand determinant people's roles in collaboratively designing and the relative skill. The quadrants of the framework are described according to the intersection between the designerly "style of guidance" – facilitation/steering – and the subject matter behind the design – conceptually described by the tension created by a linear design process – with the poles "concept driven/topic driven." The quadrants help to understand how to co-design, through which roles and how to consider the relationship between designers and non-designers. This also lets us frame some future perspectives on co-design. Indeed, as needs for participation will change for new challenges, roles techniques, methods and tools will change. According to Sanders & Stappers's (2014) speculation, "the people who are today's designers and design researchers are the facilitators and shapers of the collective dreams of the people in 2044." It is a way to say that we will shift from co-designing to taking care of collective creativity through co-design in future.

1.2.1. Challenges and benefits of embedding co-design

Co-design is also a widely used practice in several disciplines engaged with different types of research such as health and clinical research (e.g. Dimopoulos-Bick *et al.* 2019; Bird *et al.* 2021; Bolster *et al.* 2021), education studies (Mäkelä *et al.* 2018), public management (Trischler, Dietrich & Rundle-Thiele 2019), public policies

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research (Blomkamp 2018) and social marketing research (Dietrich *et al.* 2016) just to name a few. Every experience with co-design sounds different and is still difficult to find a formal and unique model to apply co-design in formal research. However, we can explore this issue by emphasising a few challenges and benefits of adopting co-design in formal research frameworks. They are both challenges for design research activities and for those scientific disciplines that are adopting co-design.

Firstly, co-design implies collaboration, communication activities, as well as the use of terminologies that often encompass technical or scientific terms. At the same time, a co-design process is an encounter among experts (including designers), non-experts and people with, sometimes very different backgrounds. All of them have a role in co-designing, even if there are key participants with multiple roles (Barcellini, Prost & Cerf 2015). By observing general frameworks on collaborative research, as transposed in co-design for research, the lack of a common language and shared terms, and the communication issues among the actors of a co-design process can be a set of challenges (Camden *et al.* 2015; Drahota *et al.* 2016; Moser 2016; Slattery, Saeri & Bragge 2020). This is also discussed in design research studies where different languages and vocabulary create a barrier (Pirinen 2016), and where the terminology for defining who the user, the participant, the co-creator, the expert or non-expert of a co-design process is fuzzy (Antonini 2021). Therefore, terminology is a challenge in co-design from two perspectives. The first is about the terms and knowledge to be managed within the co-design process for addressing a research objective as we discussed so far. And we argue this can be a common topic with general interdisciplinarity and transdisciplinary research challenges and/or barriers (Domino, Smith & Johnson 2007; Axelsson 2010; Arnold 2020; Daniel *et al.* 2022). The second is about the terminology for defining the co-design. On this second aspect converge discussions such as defining a common framework for terms such as co-creation, co-production and co-designing (Vargas *et al.* 2022) where the first is generally adopted as the broader term to contain the co-design activities and values (Sanders & Stappers 2008; Jones 2018; Vargas *et al.* 2022). However, they can be defined as co-approaches for which it is necessary to understand how they produce improved research outcomes (Grindell *et al.* 2022).

One more aspect to be discussed as a challenge for co-design is engaging and managing participants and their roles (Barcellini *et al.* 2015; Pirinen 2016; Kirk *et al.* 2021). In general terms, the typologies of participants and their roles also depend on what the design or research project's focus is. However, this aspect recalls significant discussions about the role of designers. As a few authors point out, it is possible to observe a shift from the problem-solving designer to the designer who facilitates processes (Antonini 2021) in co-design. Similarly, some studies underline challenges in identifying a new role for the researcher within co-design processes by favouring a more empathic relationship with the other participants (Kirk *et al.* 2021). In a similar vein, there is the reflection that among the researchers and the other participants, tensions in decision-making can occur in the design process (Slattery *et al.* 2020).

Some challenges also emerge from the relationship among the participants in terms of hierarchies (e.g. different working roles in the same table) (Moser 2016) that also are barriers in terms of distribution of powers in a context where a common ground for co-design is needed (Pirinen 2016; Antonini 2021).

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Co-design is also envisioned as a strategy for addressing research waste caused by a mismatch between research objectives and real benefits for people, such as patients in health research (Slattery *et al.* 2020). Indeed, it is recognised that the application of co-design can create benefits (Steen, Manschot & De Koning 2011; Steen 2013) such as (i) improving the processes of idea generation for designing a specific design output; (ii) improving the decision-making process and (iii) promoting cooperative activities and creativity, to improve the users' satisfaction and loyalty over the long term. Over the design or specific design output such as products and services, for instance, in co-designing research, the stakeholder's engagement creates benefits such as favouring the identification of the relevant research materials (e.g. research questions) and the credibility of the knowledge produced, as well as the outcome resulted easier and more acceptable for the application in a context (Camden *et al.* 2015; Slattery *et al.* 2020).

Engaging stakeholders, users and contextual participants in co-design, which in most cases are non-designers, produces benefits both for the research team and for the participants (Moser 2016). The latter generally experience positive emotions and a sense of increased skills and knowledge (Slattery *et al.* 2020) that also simplify the engagement of the involved people (Pirinen 2016). For the research team, involving non-experts (including non-designers) creates benefits such as (i) increasing the possibility of finding novel ideas and increasing creativity (Moser 2016; Pirinen 2016; Blomkamp 2018; Antonini 2021), (ii) creating a better connection between the contextual user needs and the research outputs (Camden *et al.* 2015; Moser 2016; Pirinen 2016; Blomkamp 2018; Slattery *et al.* 2020) and (iii) establishing commitment for the consequential cooperation in organisations or communities (Pirinen 2016). Consequently, a challenge for embedding co-design in formal research frameworks is ensuring benefits with a singular formal model. However, as Slattery *et al.* (2020) point out "the lack of a singular consistent conceptualisation of 'co-design' made it much more difficult to retrieve and understand the relevant literature." This makes the identification of a singular model to apply co-design in research a challenge.

In addition, co-design processes are preferred to give value to the stakeholder's voices and preferences. Therefore, as a critical point of co-design applications, some studies underline that in co-design there may occur a scientific rigour sacrifice for end-user preferences (Slattery *et al.* 2020). This is a relevant tension in co-design that underlines the need for finding a balance between multiple aspects concerning scientific rigour and an open, bottom-up design, as well as the urgent actors' needs and the long-term focus of a specific research project (Moser 2016).

In addition, the co-design impact can be considered an additional challenge due to a series of reasons such as the lack of data (Slattery *et al.* 2020; Wang *et al.* 2022). Indeed, Slattery *et al.* (2020) emphasise the importance of addressing a pressing challenge for co-design, which is creating models and evidence for evaluating the real-world impact of co-design. The impact of what co-design produces in a context, for example for designing services, is a recurrent topic in the Pirinen (2016) study on barriers and enablers of co-design for services. In this work, despite it can be considered a transversal topic, the author discusses this aspect by underlying that a lack of impact is determined by barriers such as (i) poor ability to utilise the outcomes, (ii) reliance on the implementation on a few insiders and (iii) systemic barriers to dissemination. On the same issue, Wang *et al.* (2022)

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identify a five-step evaluation framework for co-design, that is (i) considering evaluation from the beginning of the co-design process; (ii) co-defining key performance indicators and the evaluation criteria; (iii) selecting methods and techniques for the assessment; (iv) critically interpreting the results and (v) gaining additional feedback and increasing the validity. While, Ostrowski, Breazeal & Park (2021) use Zimmerman *et al.*'s (2007) four lenses for RTD evaluation (i.e. "process," "invention," "relevance" and "extensibility") to evaluate co-design in an RTD process.

For his uncontrollable nature, co-design can increase the application of resources and time (Moser 2016; Kirk *et al.* 2021). This can be seen as a critical point (Slattery *et al.* 2020) or as a requirement for adopting co-design. However, this also opens a discussion on an additional challenge. Co-designing requires involving people who may not have a direct interest in the research. Involving them, finding the right strategy of engagement, instigating collaboration and communication with a common language and preserving their interest along the process of the co-design activities is a time- and resource-consuming set of efforts (Moser 2016; Slattery *et al.* 2020; Kirk *et al.* 2021). In addition, this kind of collaboration is often regulated by conflicts and heated debates (Manzini 2014; Pirinen 2016; Andersen & Mosleh 2021) that are challenging aspects for applying co-design that require conflict mitigation skills (Slimani *et al.* 2006; Zamenopoulos & Alexiou 2018).

There is a consensus that co-design potentially produces knowledge collaboratively by mixing different fields of knowledge from the co-designers (including non-experts). However, how this knowledge is formally generated and how co-design is formally relevant for and embedded in the research process are unclear. If RTD is a kind of research that exploits the designerly ways of knowing, and by taking it for granted that this approach is used by designers (design experts), how we consider knowledge produced in the boundless context of co-design is unclear. If that knowledge is also produced by non-designers or non-design-experts, clarification is needed on how we can consider this aspect in RTD. At the same time, as one more issue addressed in this article, we highlight co-design that does not explicitly consider a generalised, formal and robust model that ensures the embedding of participative design practices within formally recognised research.

1.3. RTC: an introduction

From the first structuring of RTC (Busciantella-Ricci & Scataglini 2020a), new publications emerged on the connections between RTD and co-design. Indeed, RTC appears in literature as a way to use co-design projects for introducing the values of co-design, such as participation and dialogue, within a practice-based research experience (Jørgensen, Skovbjerg & Eriksen 2021). Also, when co-design in an RTD process is used as the main vehicle to conduct research (Aslam, Van Dijk & Dertien 2019), its role as an RTC process is clearer. In parallel, RTC has been used as a methodology to conduct RTC activities with older adults in a doctoral research process engaged with the topic of Eudaemonic Design (Mikus 2023). In this case, RTC is used "as a reflexive form of inquiry to foster participant engagement while collaboratively considering the research questions" (Mikus 2023). Also, Bakırlıoğlu & Doğan (2020) propose a "research through co-designing" process as

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an adaptation of the steps for "research through designing" which in turn is based on Schön's (1983) reflexive practice framework to accommodate the co-design processes. Walsh *et al.* (2012) claim to use RTC as they claim to use a co-design approach in their RTD "because participants were part of a culture that values partnership […]" among different users. It is the case where "design partners do more than just inform the direction for the future, they are active participants in the next design." However, in some cases (e.g. Taylor 2017; Ostrowski *et al.* 2021), even if the usage of co-design is an integral part of an RTD approach, the process itself is presented as "through design" without any mentioned change concerning the mental model for managing the collaborative process in the RTD process. Similar relationships and challenges emerge from those works (e.g. Kerr *et al.* 2022) where RTD is used as a research method, and a reflective process for discovering knowledge through a design work, that embeds co-design as an approach to plan the incorporation of the multiple stakeholder groups and the related needed applications.

Recent contributions introduce "participatory research through design" (Wilde 2020, 2022). It is presented as a methodology for embedding participatory values into the RTD process. Even if a specific model is not presented, what is considered highly relevant for this article is the perspective that they offer about the roles of designers in participatory RTD. Every designerly approach to conducting research, if struggling with collaboration and participation, creates tensions in the traditional designer position's meanings, values and roles. For instance, in participatory RTD "the designer is not the expert" (Wilde 2020). Rather this role collaborates with the other stakeholders and recognises their (non-designers) designerly contribution. Also, Wilde (2020) underlines that participatory RTD "brings differing perspectives to bear on creative decision-making; and enables researchers to navigate tensions of difference, articulate more precisely and realistically what might be meaningful for stakeholders with divergent values, and identify which benefits to aim for." Diversity in design research is a core concept. And it lets us recall the direct relationship between RTD – action research, and co-design – Participatory Action Research (PAR). According to Stewart (2014), "co-design can be seen as a type of Participatory Action Research and often explicitly draws upon an action research methodology. The important contribution of design to collaborative action contexts is its generative mode of inquiry." In parallel, some explorative approaches are emerging by embedding similar topics such as the "action research through design" (ARtD) methodological approach (Cruz *et al.* 2022). It allowed researchers to develop a framework for co-design processes to conceptualise and analyse design in collaboration. This framework provides three design circle phases through which people move from "Informative" to "Consultive," "Participative" or "Collaborative" levels of collaboration.

Both design and action research – as well as PAR – are engaged in changes. In general terms, design and action research are different even if aspects such as the design process and the action research process present similarities and differences (Swann 2002; Stewart 2014). Similar to RTC, PAR is "an approach characterised by the active participation of researchers and participants in the coconstruction of knowledge" (McIntyre 2008). RTC considers co-designers all the members of the RTC process. The PAR process may help the understanding of the RTC fundamentals. Specifically, PAR describes a "recursive process that involves a spiral of adaptable steps that include" (McIntyre 2008) (i) questioning, (ii) reflecting,

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(iii) developing and (iv) implementing and refining. PAR is therefore "a research paradigm within the social sciences which emphasises collaborative participation of trained researchers as well as local communities in producing knowledge directly relevant to the stakeholder community" (Pant 2014). This knowledge intends to contribute to the theoretical corpus of the social sciences, and it also contains a social change agenda (Pant 2014). PAR and RTC present differences such as different purposes, but they present a common connection with the participatory paradigm (Heron & Reason 1997; Lincoln, Lynham & Guba 2018). In terms of process, PAR may inspire RTC even if the goal is different.

Finally, a recurrent term that can be connected with RTC is the "co-production of knowledge." It is used as a terminology to understand how participatory processes allow communities and target groups to produce new knowledge for a discipline (e.g. Heaton, Day & Britten 2015; Rycroft-Malone *et al.* 2016; Djenontin & Meadow 2018; Redman *et al.* 2021; Gerlak *et al.* 2023). And this may have a connection with the production of knowledge through co-design. For instance, Schwoerer *et al.* (2022) propose the CO-DESIGN framework with eight elements each representing a salient process or product in public administration research and/or practice. The eight elements are (C) co-production of knowledge; (O) open science; (D) developmental and comparative perspectives; (E) equity and diversity; (S) social innovation; (I) inclusive participation; (G) goal-oriented research; (N) new possibilities (for research).

In general terms, the frameworks emerging from research in the co-production of knowledge can affect the formalisation of a model to use the RTC theory.

1.4. CST for RTC

Why is the CST here reported as a relevant aspect of RTC? And, how is the CST conceptually connected with RTD and co-design? We provide a discourse to address these questions. Firstly, in CST it is essential to define the meaning of the word "control." This concept stands for two meanings, that is controlling in terms of (i) testing a system, and (ii) preventing a specific behaviour of the system (Neculai 2005). Essentially, controlling is the main activity of this system where there is a subject that assumes the role of the controller (that executing the action of control), and an object (a process, a system or a device) – technically a control plant – which is the object the control is acted upon (Bubnicki 2005). If we consider the relationships between the controller and control plant, we can consider around four cases that Bubnicki (2005) describes as (i) open-loop system without the measurement of disturbances; (ii) open-loop system with the measurement of disturbances; (iii) closed-loop system and (iv) mixed (combined) system. Essentially, the difference is determined by the role of system output. In an open loop, it does not affect the control action of the system. In the closed loop, the output depends on the input and the system allows the creation of the desired output through a feedback system. This is the reason why the closed loop is considered a feedback control system. The feedback loop can be positive or negative. In the first case, positive feedback increases the status of a system. In negative feedback, the system tends to be stable, in a sort of system equilibrium (Levine 1996; Bubnicki 2005; Iglesias & Ingalls 2009; King 2021).

A lot of biological systems can be explained with the CST (Iglesias & Ingalls 2009). For instance, fruit ripening is an example of positive feedback, while

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homeostasis in the human body is a traditional example of negative feedback in a closed system (Michal & Klein 2015). Negative feedback is also discussed in public policy studies (Baumgartner & Jones 2002; Bardach 2006; Zahariadis 2008; Howlett 2009) to understand how the self-correcting mechanisms can reinforce the stability of a system (Baekgaard, Larsen & Mortensen 2019).

Indeed, CST is widely known in the application of engineering (King 2021), systems biology (Iglesias & Ingalls 2009) and automation (Levine 1996). It is also a mechanism that can embed mathematical theory on how to approach co-design (e.g. Censi 2015). However, why connect CST to RTD? Specifically, we previously referred to the second-order cybernetic as one of the most influential RTD models (Jonas 2015) for applying co-design variables to it. At the same time, we know that "Cybernetic or control theory is a general approach to the understanding of self-regulating systems" (Carver & Scheier 1982) where "the basic unit of cybernetic control is the feedback loop" (Carver & Scheier 2012). Indeed, cybernetics is essentially the control theory as it is applied to complex systems (Britannica 2023). RTD which assumes co-design as the main system to be controlled is a complex system. At the same time, RTD has been discussed in the logic of cybernetics (Glanville 1997, 2005; Jonas 2007, 2015; Sweeting 2017). Therefore, If we assume that RTD is a typology of design research, and the latter is a cybernetic process of experiential learning (Jonas 2015), we can use the CST as the basic theory to create a practical model for understanding RTD and the related role of the co-design process on it. This is also in line with research studies that tend to suggest that design research is a variety of second-order cybernetic (Sweeting 2017). According to this view, RTD determines the whole system based on the negative feedback of the closed loop, and co-design is the open-loop system made by the controller and the control plant. If we assume that the co-design is the open-loop gain, and RTD is the whole system, we may assume that there is a feedback loop that allows us to make the system stable by using co-design. Consequently, we may measure and control the transfer function of the control system. Quantifying and measuring the whole system is an objective of this work for also finding rigorousness and robustness to the system behind the RTC conceptual model.

1.5. Aim

The goal of the research we are presenting in this article is to develop a cognitive model for RTC. Indeed, as co-design practices and requests increase among the design community and society, more knowledge is needed about collaborative design processes. In contemporary society, designing means co-designing. It implicates differences in RTD. Literature provides discussions, comparisons, instruments and examples that very rarely distinguish if knowledge is produced by designers or co-designers in RTD. Generally, RTD considers designers/researchers as the producers of knowledge. It means design experts (Manzini 2015). However, in a typical co-design process professional design experts collaborate with researchers, citizens and several different people non-experts in design. This variety is a resource for the co-design process. However, rarely literature provides a discussion on what happens if they are the "non-design-experts" in strongly affecting the production of (design) knowledge rather than specific roles of the design research area, such as the designers-researchers

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(Cross 2006). Co-design literature provides interesting contributions to learning, and conversational processes aimed at underlying the value of the contribution from "non-design-experts" along the participative design processes. Rarely discussions on how these aspects may modify the essential design research foundations are provided. In other words, we do not know what happens to RTD if the process is entirely operated with collaborative and participative dynamics. Since the design literature debate on the foundational and epistemological issues of RTD started, we know that this kind of design research deals with creating a consistent concept to create its academic standards and reputation, as well as to prove that research answers obtained by designerly procedures are of equal quality respect to answers provided by other disciplines (e.g. Jonas 2015). If we assume that design knowledge resides in people, products and processes (Cross 1999, 2006), then it is possible to affirm that forms of design research – as a practice for producing design knowledge (Manzini 2009) – such as RTD are influenced by people, products and processes. Indeed, several contributions in design literature on RTD address the "product" of design as an artefact that embeds knowledge for finding research answers. In parallel, the process of making those artefacts is also the subject of the investigation to understand how designers excogitate manners to produce new knowledge with a designerly approach. The literature review presented in the previous paragraphs mainly describes an overview of these aspects and the mentioned contributions mainly consider how "designers" as "design experts" and the related processes can represent a robust body of knowledge for considering RTD as an academic and formal type of research. However, what happens to RTD robustness when design experts with non-experts collaborate in a design process – by creating a co-design process – or better, what happens when non-experts collaborate in a designerly process for finding a research answer – is not clear. At the basis of this article, there is the assumption that a co-design process, where potentially everybody can participate, is different to a traditional design process driven by the dynamics of an expert designer. For instance, the co-design process needs to consider aspects such as dealing with conflicts among the participants; or it constitutes a basic perspective for the co-creation processes in adopting citizen science perspectives (see e.g. Eckhardt *et al.* 2021). It means that co-design needs to consider variables that make the RTD process more complex to an RTD process where a trained designer tries to find a research answer (mainly by herself or himself). A traditional perspective on RTD assumes the designer is the core person of the RTD process. Its RTC variant assumes groups of multiple people – experts and non-experts, or only non-experts – as the core persons of the whole designerly-research process. This aspect is less debated in design literature that addresses RTD issues. Also, as Boon *et al.* (2020) discuss by talking about the participation concept among RTD themes, "while many participatory design projects can be considered as a form of RtD, such work is not often discussed in RtD-related papers." At the same time, participatory design projects do not discuss how co-design may represent a new frontier of RTD, or it can go beyond, or it could question the dynamics of RTD. Therefore, opening the discussion on these aspects is the overall goal of this article. And introducing a cognitive model for doing RTC is the objective. It is an alternative model for applying RTD in the case of co-design and according to the participative paradigm (Lincoln *et al.* 2018).

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1.6. Significance

We argue providing a robust discussion on co-design at the core of the RTD process is needed. Firstly, it is important to understand more specific aspects of RTC because it enables consideration of the co-design as an integral part of the research process. Consequently, it gives robustness to RTD processes that assume co-design at the core. Co-design is becoming a pervasive process adopted transversely through a lot of diverse research even from different disciplines. Therefore, it is even more important to understand how to integrate a specific instance of co-creation through design within a research process, that is clarifying the role of co-design in RTD processes. Indeed, while RTD has been discussed in design literature, RTD that assumes co-design has been poorly considered as a perspective to be theoretically defined. However, co-design implies several dynamics and processes that make the design process different from a traditional non-collaborative/participative design process. Co-design implies aspects such as empathy with other participants (Smeenk, Sturm & Eggen 2019), (constructive) conflicts (Manzini 2014; Zamenopoulos & Alexiou 2018; Andersen & Mosleh 2021), tools and techniques (Brandt, Binder & Sanders 2012) that substantially differ from a traditional design process mostly regulated by designer-alone processes. Consequently, it is needed to make a distinction between what is defined as RTD and what can be defined as RTC. Also, this article underlines why and how a new model that better describes what can be defined as RTC should be framed and discussed. In fact, from a certain perspective, RTC is RTD that assumes co-design at the core of the process. However, a formal, unique and robust RTD operative process is still difficult to generalise. Therefore, RTC may contribute to both integrating co-design in RTD and at the same time, giving a reference and robust model to RTD thanks to the adoption of the CST. In addition, co-design is largely adopted in several research processes, but it is still considered a collaboration process where design is detached from pure research. This perspective risks distancing co-design from the design research debate that discusses RTD and "design as research" frontiers (Frayling 1993; Jonas 2015). Finally, the RTC model proposed in this article attempts to contribute to robustness by using co-design as the main process for finding a research answer, independently from the research discipline.

All these aspects indicate the need for more work on the subjects presented in this contribution because RTC, in summary, leveraging on (i) augmenting the discussion on co-design in RTD that is poorly considered as a determinant of RTD variables; (ii) clarifying how co-design applied in different research processes can be a consistent part of the research as it happens in RTD and (iii) investigating the possibility of providing a formal, unique and robust model for conducting research through the medium of co-design. Finally, none of the models presented in the literature allow us to measure specific variables, not in RTD, RTC and co-design contributions. Firstly, it is because design processes are almost impossible to compute both in terms of planning and creating a prediction of how it can be conducted. Designing a model to simplify the design, development and computation of specific variables is needed to give robustness and generalisation to all the diverse models and practices that are engaged in both RTD and co-design. Therefore, by introducing the RTC model it will be possible to (i) understand how gaining knowledge in an RTD process by enabling design collaborations of a

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wide variety of diverse people and resources; (ii) simulate an RTC process by also taking advantage of the opportunity to use the computational features of the model; (iii) measure and validate research processes that adopt co-design; (iv) enhance the possibility to adopt co-design in society by decreasing the efforts for designing and managing participatory processes; (v) improve design research opportunities by giving a theoretical model for future research activities (e.g. through doctoral thesis) and (vi) develop additional computation model (e.g. based on artificial intelligence) to understand how to foresight co-design processes for doing research.

2. Methodological approach

We assumed to design the RTC model by adopting a speculative design approach (Raby 2008) and by adopting a "what if" question (Dunne & Raby 2013) specifically related to "what if exploring the idea of RTC by assuming CST with negative feedback as the main cognitive model?" Consequently, we used an RTD approach for designing the RTC model assigning variables to a control feedback-loop system to control the state. We combined a general feedback-loop model (Figure 1) with variables that can represent, on the one hand, a general RTD approach, and on the other hand the basic elements of a co-design process. We followed the general process of goal-seeking (Figure 2) of the CST for activating a loop cycle according to an RTD approach and introducing co-design variables in the design of the model (Figure 3). The control theory has been used as a strategy to select the appropriate input (as a research question for RTC) giving an output (or research answer in RTC) (Figure 2). The control theory presents two types of control loops: open loops and closed loop (feedback control) (Levine 1996; Iglesias & Ingalls 2009; Carver &

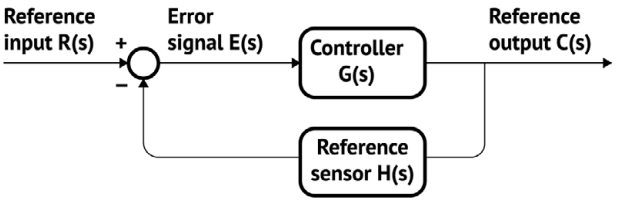

Figure 1. A general feedback-loop system.

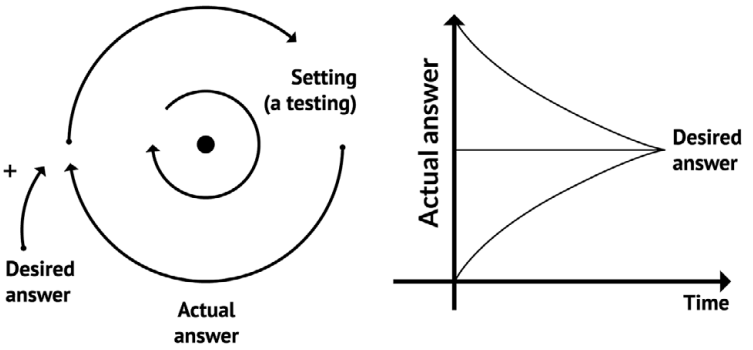

Figure 2. The goal-seeking process. Left (system structure), right (pattern structure).

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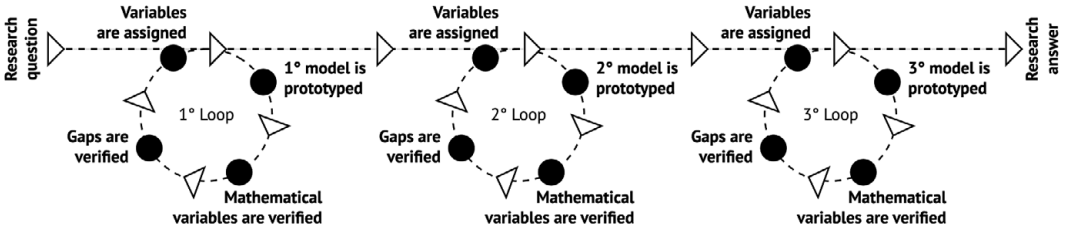

Figure 3. A graphical summary of the loops for designing the model.

Scheier 2012). Open-loop systems are systems where the output of the system does not affect the input. A closed-loop control system has a retro-feedback to generate a control action to bring the controlled process variable to the same value as the set point in input. Closed-loop systems are designed to automatically achieve and maintain the desired output condition by comparing it with the actual condition. It does this by generating an error signal which is the difference between the output and the reference input. The difference between the actual and desired value of the process variable called the error signal is applied as feedback to generate a control action to bring the controlled process variable to the same value as the set point. Stability is an important characteristic of a control system. For the bounded input signal, the output must be bounded, and if the input is zero, then the output must be zero, then such a control system is said to be a stable system.

As a method, we applied the CST according to a basic closed-loop control system (Figure 1) according to the transfer function of the positive feedback control system (Levine 1996). We used the process of designing the model as the epistemological medium to gain knowledge about RTC inspired by Jonas (2015). Essentially, the process for designing the model is the iterative loop of the same mechanism where, after assigning a research question, we managed it according to the following steps; (i) we assigned the variables to the model to first connect RTD and co-design principles with the CST; (ii) we designed the prototype of the model; (iii) we verified the balance of the system through the transfer function and (iv) we finally compared the results with the gaps of the literature that we previously identified. In the second and third loops, we followed the same process steps by firstly refining the variables and the model prototype for each loop, as well as verifying the reliability of the obtained results through mathematical applications and comparison with the existing literature on RTD. Regarding the development of the model prototypes during the loops, we conceptualised their simulation in different backgrounds by presenting our RTC theory and its possible application in the field of applied ergonomics and human factors (Busciantella-Ricci & Scataglini 2020a); its application as a logical aid to prepare for a shared scenario of a research process (Scataglini & Busciantella-Ricci 2020); as a model able to visualise the nature of places such as maker-spaces and FabLabs (Scataglini & Busciantella-Ricci 2021a); as a model to reflect on the future of design education (Busciantella-Ricci & Scataglini 2020c); for connecting RTC with ergonomics principles (Scataglini & Busciantella-Ricci 2021b) and policy-making (Busciantella-Ricci & Scataglini 2020b), and for reflection on the connection between RTC, Design for All and Policy Ergonomics (Busciantella-Ricci & Scataglini 2021). We used the designed model as a speculative design proposal (Raby 2008) adopting a speculative research approach (Wilkie, Savransky & Rosengarten 2017) to discuss theoretical aspects

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within seven peer-reviewed papers in three international conferences and one journal. We used the RTC model as a "model for" that is "purposive and therefore essentially cybernetic, intended to allow us to act on that world, to find something out, to see what would happen if" (Glanville 2005). We also positioned the RTC model by considering a paradigm shift towards the participatory ones (Lincoln *et al.* 2018) also for its "subjective-objective ontology"; an epistemology with a "critical subjectivity" and four ways of knowing, i.e. experiential, presentational, propositional and practical; and a "methodology based on co-operative relations between co-researchers" (Heron & Reason 1997). In terms of referencing the synthesis of our idea of the RTC model, we considered:

- Jonas's (2015) perspective on RTD as a synthesis of how design works as an epistemological medium in research;
- Owen's (1998) model for using and accumulating knowledge; we created a synthesis by merging the two realms in the model and by assigning at the realm of the practice the principles and the processes of the co-design;
- the Knowledge-Relevance (K-R) Model (Krogh & Koskinen 2020; based on Bang *et al.* 2012) by specifically taking the concept of "relevance" as related to the gap generated between the research question and the research answer, and the "design experiment" concept as an element that, in our idea of the RTC model, embodies the meanings of doing co-design in the RTC theory;
- Bakırlıoğlu & Doğan (2020) model that accommodates the co-design process within the RTD influenced by Schön's (1983) reflexive practice framework; it represents a first-stage reflection on how embedding co-design in a structured research process based on RTD; however, we argue it needs to be integrated with a more robust reflection of what are the variables determined by the concept of "research";
- a general basis of the feedback-loop system (Figure 1) to create a robust basis to generate a new synthesis of the aforementioned concepts.

3. Results

The most advanced model to address RTC in simulation settings is presented in this study as the major outcome. We offer an overview of the work in creating the RTC model based on our RTC theory.

3.1. The basic RTC model

In all our speculative work, we used the same basic model for each situated emulative application context. It is the RTC co-model (Figure 4) that we integrated loop by loop with additional knowledge acquired during the speculative works. As a result, after attributing variables to the RTC process based on the closed-loop CST, it was possible to compute the research answer, *C(s)* of a research question in *R(s)* minimising the error *E(s)* expressed as the difference between actual (research answer obtained) and desired value (pre-fixed research answer).

This can be expressed as

$$E(s) = R(s) - C(s)H(s). \tag{1}$$

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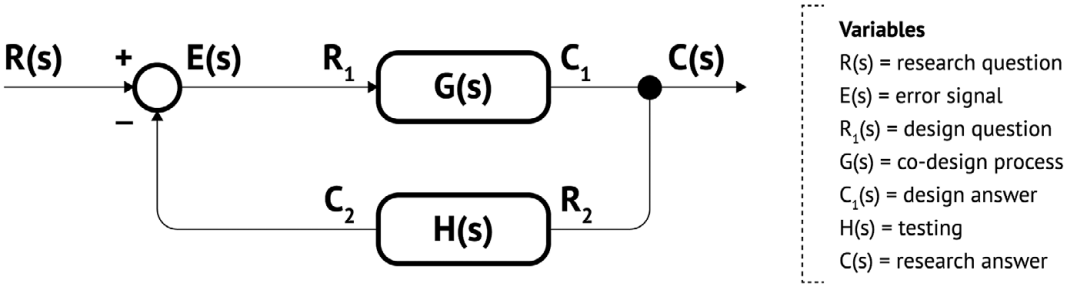

Figure 4. A co-model based on a closed-loop system in RTC.

The error signal *E(s)* is applied as feedback to generate a control action to bring the controlled process variable to the same value as the set point.

The goal of the RTC system is the transfer function representing the co-design process *G(s)* of the system that is represented as the ratio between the research answer *C(s)* and the input of the research question *R(s)*, as expressed in equation (2) below

$$G(s) = \frac{C(s)}{R(s)}, \tag{2}$$

where

$$\begin{aligned} C(s) &= G(s)R_1(s) = G(s)[C(s) - C_2(s)] = G(s)[R(s) - H(s)R_2(s)] \\ &= G(s)[R(s) - H(s)C(s)] = G(s)R(s) - G(s)H(s)C(s). \end{aligned} \tag{3}$$

Putting this equation (3) into the previous equation (2), we can express

$$G(s) = \frac{C(s)}{R(s)} = \frac{G(s)}{1 + G(s)H(s)}, \tag{4}$$

where *G(s)H(s)* is the transfer function of the loop that is the product between the co-design process and the co-testing. Therefore, in the co-design process *G(s)* the team of co-designers *Co* (assuming that is necessary to have co_i and co_j > or equal to 2) is expressed by equation (5). Ideally, it is a cross/multidisciplinary team where each co-designer is a person from different fields, experiences and backgrounds that can take a fundamental role into the co-design process due to their diversity. By observing this system, we identified a possible insight. We observed that co-designers, as single key elements of *G(s)*, are variables that should establish a connection to correctly work. As we know, communication and interactions among the participants are some of the challenges and characteristics of co-design (Moser 2016; Pirinen 2016; Blomkamp 2018; Slattery *et al.* 2020; Antonini 2021). Consequently, the co-designers are connected like a network that communicates with the language of co-design, or through the language facilitated by the co-design tools. If the co-designers can be seen as nodes of a network, we may assume they are in a "network" of neural mechanisms (Tang, Tan & Yi 2007). They can act and communicate as computing systems of biological mechanisms that can be used to train and simulate a research answer to gain the fabrication of the knowledge.

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$$\mathrm{Co} = \sum_{i,j=1}^{n} \mathrm{co}_i \times co_j. \tag{5}$$

As a consequence, giving a design question $R_1(s)$, the co-designer should use the design tools T in the co-design process $G(s)$ to solve the design answer $C_1(s)$ such as equation (6):

$$G(s) = \frac{\mathrm{Co} \times T}{R_1(s)}. \tag{6}$$

A design tool (T) is a context-related set of actions, thoughts or objects that makes possible other actions, thoughts or objects for the accomplishment of design-related tasks.

The RTC model works as a mechanism for producing, understanding, evaluating and iterating knowledge acquired with systematic feedback loops of cycles. Every loop of the RTC process is a chance to gain knowledge for understanding the research question $R(s)$ and advancing the chance to reach the research answer $C(s)$ by exploiting creativity, collaborations, processes, approaches, empathies and all the values that can be expressed in the co-design process $G(s)$. The entering of the co-design process is itself determined by an input R_1, the design question, and an output C_1, the design answer as an effective outcome of the co-design process. This outcome can be tested within the $H(s)$ variable to verify if the outcomes of the co-design process answer the research question $R(s)$. In this process, diversity, in terms of different people (with diverse skills, backgrounds, needs, capabilities, cultural, political, economic status, etc.), is the real resource of the whole process. The greater the diversity of people in the co-design process, the greater the possibility of feeding the system with new loops will be. More loops mean increasing the possibility of gaining more knowledge. And, as a direct implication of this mechanism, more possibilities to gain knowledge means a greater chance to reach a clearer answer $C(s)$. The clearness of the answer is therefore proven by the $E(s)$. If it does not produce an error, it means the system recognises the answer of the co-design process (i.e. C_1) as valuable to answer the whole system (i.e. $C(s)$). $H(s)$ tests that C_1 produces or does not an error of the system reported through $E(s)$. It essentially describes a self-validation process of the RTC system. In other words, the loops produce and stabilise the turbulence that the co-design process in $G(s)$ determined through the multiple creative activities, and through the diversity of the people. However, this turbulence is a resource the whole system may use to stabilise a research answer through the loops guaranteed through the mechanism that describes the negative feedback in the CST mechanism. In summary, more loops (i.e. more possibility to gain knowledge) give a more accurate answer by reducing the error answer of the system. It is how an intelligent system works.

3.2. RTC as a learning system

$G(s)$ can be represented as a neural network in which each co-designer is a node that communicates with one or more co-designers. This co-designing neural network mechanism is a computational neural model used to train and simulate the elaboration of a research response through a co-design process while minimising the error between the acquired research answer $C(s)$ and the predetermined

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research query *R(s)*. As a result, the nodes function similar to neurons in biological systems, augmenting consciousness through learning and knowledge creation. Human intelligence is defined as the capacity to do difficult tasks that require judgement, creativity, empathy, interaction and multi-domain knowledge. This is distinguishable likewise based on subjective experience. Each co-designer in RTC displays his or her unique consciousness. In *G(s)*, the co-designers are nodes, as neurons of a brain (Figure 5), with different backgrounds, knowledge, competencies and relational intelligence concerning designing.

In the RTC co-design process, *G(s)* is seen as a perceptron (Rosenblatt 1957) where to the inputs we are attributing the nodes that are the co-designers (co) characterised by weights w_i (experiences). Therefore, it is possible to describe the transfer function inside *G(s)* as equation (7):

$$G(s) = \sum_{i=1}^{n} w_i x_i. \tag{7}$$

The perceptron produces output that is the exit of a design process that can be 0 or 1. If it is 1, we obtain the response $C_1(s)$ to *G(s)*. Otherwise, in the case of 0, we are not obtaining a response $C_1(s)$. In RTC, weights w_i are variables that determine the understanding of diversity in terms of those factors that can describe the differences among the people participating in the co-design process.

3.3. Diversity and inclusion variables

In designing the RTC model, we also reflected on the meaning and the value of diversity and thus inclusion in the co-design that substantially influences the whole research process. We started from the assumption that, even if some peculiarities are similar, every person is essentially unique from every point of view. This is a resource to be considered in the co-design process that determines the systematic inquiry through RTC. Therefore, from Figure 5, we designed a polynomial to understand how to consider diversity in *G(s)*. Diversity is a core feature in

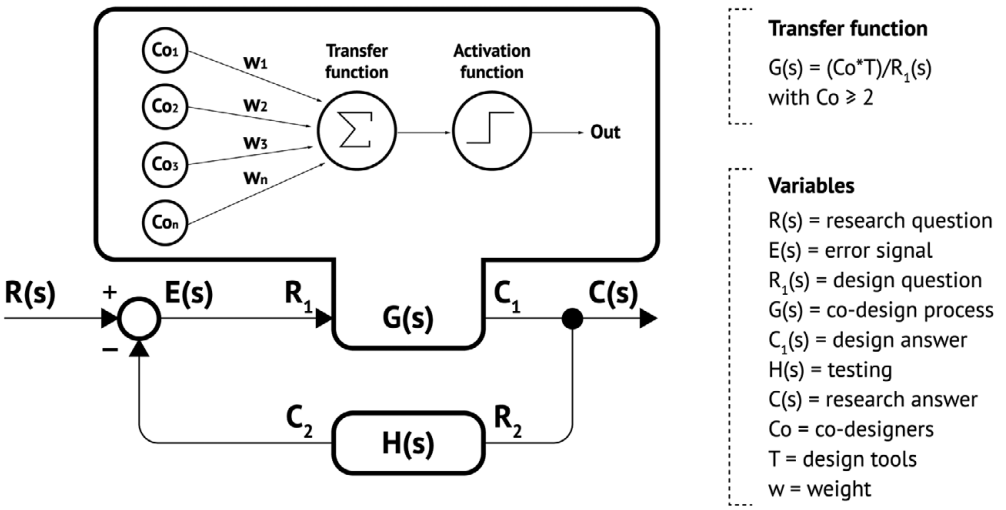

Figure 5. Graphical representation, variables and transfer function of the RTC model.

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co-design and needs an interpretation in RTC. Consequently, we designed the polynomial of diversity (PoD) because it considers exclusion factors and some elements that can describe how diversity can be addressed. Addressing exclusion factors is a way of considering the concept of inclusion through multidimensional levels of inclusion/exclusion (Taket *et al.* 2013). Therefore, we adopted a framework of five inclusion/exclusion factors (Busciantella-Ricci *et al.* 2017; Busciantella-Ricci & Scataglini 2021) which allow us to consider physical and cognitive (a), cultural (b), political (c), economic (d) and social (e) factors among the diversity domains of the people. We assigned the five exclusion factors (a, b, c, d, e) as values to be multiplied by the elements (x, y, z) that guarantee the diversity in the RTC system. Specifically, these elements are the participation (x) of the different people/actors in the RTC process; the context (y) in terms of a significant interaction of the design beneficiaries with the context; the personalisation (z) as an intrinsic attitude of the self/auto-regulation feature of the RTC system in favour of the different people/actor's needs. The multiplication of these elements with the five exclusion factors defines the PoD as a P or polynomial in the RTC process. It is described by equation (8).

$$P = (a + b + c + d + e)(x + y + z). \tag{8}$$

The polynomial describes the weight as we discussed in the previous paragraph where we introduced equation (7) and the variable weights w_i. P describes the weight that is learning of the perceptron. It categorises the diversity of each co-designer in the co-design process $G(s)$; they are nodes of that brain. The sum of the products of the weight and the input in each node are computed at perceptron function $G(s)$ that need to pass a threshold that fires. The firing represents the capability or not of the success to determine the research answer through a co-design process $G(s)$. The diversity's variables – accordingly, exclusion factors and the assigned elements of diversity – can describe how diversity collaborates in $G(s)$ and RTC. The RTC model is a neuronal network where all the diversities collaborate. The threshold to exit $G(s)$ is crossed or not if this diversity is respected. If the answer (C_1) is representative of the different weights within the co-design process, there will be more chances to cross the threshold.

4. Discussion

As a tentative formal definition, RTC is a mathematical model of cognitive control for understanding how co-creating knowledge through a co-design process in a wider research process. In the real world, RTC may work as a strategy for those who adopt co-design processes, experiences and knowledge as a medium to give answers to their research questions. If supported by the related model, RTC is useful to be adopted not only by designers-researchers but also by citizens, policy-makers and social innovators. RTC is exploitable in a wide range of contexts by improving the possibility of collaborating through co-design thinking in complex systems and contexts. Indeed, control theory and the feedback loop allow stability and self-regulation to the research system without losing relevant properties such as creativity, participation and conflict in the co-design process. Specifically, RTC is an application of the CST that includes a research problem (assigned or related) to a co-design process in RTD. This reinforces "co-design" and RTD and merges

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them into a unique discussion. RTC is an opportunity to make RTD and co-design evolve.

4.1. RTC and RTD

The RTC model supports rigorousness and relevance as one of the most common concerns in the RTD debate (e.g. Findeli *et al.* 2008; Chow 2010; Jonas 2015). Indeed, CST as the behind model supports the interpretation of the variety of possible RTD processes as described in the literature. Specifically, while *G(s)* gives space to the designerly ways of addressing research problems and challenges, the outcomes of that process can be tested in *H(s)* by directly referring to the research question *R(s)* and by simulating and measuring it iteratively. Also, RTC introduces some features and topics within the RTD discussion. By considering co-design as the main focus of the research process, the RTC model introduces the auto/self-regulation feature. It is a property of the feedback loop that may be relevant to be deeply studied in systematic RTC or RTD experiments. Conceptually, it confers to the research system the possibility of being an autopoietic system (Maturana & Varela 1980). The RTC model, as an auto/self-regulated system, generates design knowledge by the same entities that learn via the system – through the collaborative processes in *G(s)*. This system may be thought of as an autopoietic learning design system. It embeds instructional processes in the same processes that the model's variables describe. The more consistent and diverse the cooperation in the co-design process *G(s)* is, the more the system may expand via the diversity of the same players in *G(s)*. The RTC model encourages variety while also supporting equality.

Secondly, concerning the RTD discussion, RTC recalls the attention on the concept of "materiality," "object" and "artefacts" and their related meanings. What emerges from an RTC process does not necessarily have a tangibility to be observed. It is unclear how RTD can consider the intangibility of design as an "artefact" to be observed and through which to gain new knowledge. We argue that RTC reinforces the Findeli and Jonas perspective on RTD following the hypothesis of the "eclipse of the object" (Findeli & Bousbaci 2005).

Third, and probably the most important, RTC introduces the concern of co-design and participation; and this begins to be recognised as one of the topics to be addressed in the RTD discussion (e.g. Boon *et al.* 2020). Co-designing potentially changes the paradigm we think about the word "design." Collaborating within a design process introduces significant changes in the approach, methods, tools, processes and the general conditions of the design context. RTD is different from RTC as designing is different from co-designing with a collaborative and participative mindset and attitude. This aspect also opens a discussion on the role of those we generally call "designers" or "designers-researchers" or researchers engaged in design research or reflective designers. In any case, access in *G(s)* with real participation and a collaborative mindset means being part of the system with no labels.

4.2. RTC and co-design

Who is the co-designer within the RTC process? According to the RTC perspective, the co-designer in the RTC process is a person who takes part in the research

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process without any distinction on experience, background, capabilities, cultural, economic, social or political status. In our idea of RTC, potentially, anybody could apply an RTC process. Are those considered "designers-experts" useful for the RTC process to take positions, facilitate, stimulate discussions and conflicts and do any other kind of designerly activity? From the RTC perspective, the right answer is "not necessarily." Let us try to explain this. Entering the RTC process means that the RTC system enables the training as the people enter the system. Conceptually, as the system takes the input ($R(s)$), it finds a balance with its own resources, including human resources. This aspect would be clearer by thinking about the entering process in $G(s)$. We described the "weight" as the variable that contributes to making every person valuable because it is different to any other person in the same system. The more the diversity is represented in terms of different weights, the more the system can find the output of the system. It means that RTC values and favours diversity as a favourable condition for the whole research process. This is a determinant aspect of co-design because diversity can also favour creativity and innovation by increasing the possibility of finding the answers to the research questions. Technically, the PoD is the description of those variables that guarantee the system takes into consideration diversity, inclusion and thus a real co-design experience. Therefore, the designer, as a role, will be determinant as it will be determinant in any other representative role in the co-design process. We argue that changing the perspective on the role of "designers" may also help the design community to evolve in new forms within a constantly changing society. We argue that RTC helps to reflect on these aspects. In other words, RTC makes tangible and computable the roles of the co-design actors through their weights and their position within the system. It emphasises a relevant aspect for designing co-design processes; i.e. planning criteria to involve participants in a co-design process. This aspect is one of the most relevant to make the co-design process participative and representative within specific research processes. This aspect may increase the potential of co-design to be not only a way to participate and democratise the design and research process but also a robust way for conducting research. The citizen sciences approach is a potential example. It can potentially benefit from adopting RTC as a robust modality to embed co-design for conducting formal research. In this context, RTC may help to increase the introduction of systematic co-design activities in scientific research.

Also, RTC formally helps the co-design culture to evolve in terms of knowledge production. As an instrument, RTC serves the participatory and collaborative design-based processes to gain a new kind of knowledge from the values and the process of co-designing and co-creating. Co-design is $G(s)$ in the RTC system. Therefore, it is the set of variables that determine the trend of the whole system, that through retro-feedback properties is also able to control the instability of the process and allow the iteration; again, with co-design, loop by loop. Potentially, this helps to systematically adopt co-design in a wide variety of situations and conditions increasing the possibility to adopt collaborative practices in complex contexts and by systematically gaining new verifiable knowledge.

Moreover, the whole RTC system can be simulated. It means solving a series of latent problems for co-design. Traditionally, co-design processes are not predictable. Indeed, they are subject to several factors, field conditions and uncontrollable variables that make the simulation difficult or impossible; or, if possible, really expensive, as it is expensive in terms of work and human resources designing the

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co-design and the collaborative research processes. Also, in this case, simulating all the variables is even impossible. RTC allows the simulation of the co-design and the entire collaborative research process. We do not yet have sufficient data to say that RTC is a model that allows us to make predictions on co-design, but we can affirm it is a starting point. For instance, through the RTC variables and the PoD, it is possible to consider new ways of understanding how to build the set of co-design processes according to the diversity of the people that should be involved. Also, ideally, these variables may help in simulating what kind of outcomes can be expected according to the kind of diversity in the process; or what kind of people should contribute to the co-design process for reaching a specific research answer. RTC may be useful to build a computational model for simulating these difficult aspects of the process, increasing the level of quality, creativity and inclusiveness of the whole research process. Artificial intelligence (AI) fields of study may also benefit from this starting point on RTC. And through RTC, it can be easier to connect co-design with advancement in AI. However, our intention was not to close in a set of rules on the discussion of RTD and co-design. Instead, we felt the need to create an interpretation of the RTC idea by discussing its genesis in an established theoretical framework. We do not exclude changing our perspectives in the future, especially after doing simulations and in-field experiments which is one of the limitations of this research. Another limitation is the lack of testing examples or cases that can support or drastically change our perspective on the RTC concept.

Also, the RTC model facilitates the pursuit of the co-design challenges presented in the introduction paragraphs of this article. Frequently, co-design processes are challenging because of different languages, terminologies, power balances, hierarchies and situations that also require conflict negotiation (e.g. Moser 2016; Pirinen 2016; Antonini 2021; Kirk *et al.* 2021). All these aspects are related to the concept of human diversity and they also produce benefits for co-design to improve creativity and widen the borders of the research process. At the same time, they increase the time and resources needed to be adopted in a research process. The RTC model potentially creates the condition to prevent, compute and rigorously plan these challenging aspects for co-design. And it does it by taking into consideration how they may impact the whole circle of the research process. In practical terms, through the $G(s)$ variables, it is possible to create in advance an overview of how these challenges can affect the whole system. Consequently, it improves the decision-making on what kind of participants can create the best conditions for both gaining the benefits of diversity and reducing the risk of transforming these challenges into barriers. Weights (w) and design tools (T) are the variables that allow us to compute and plan the previously discussed aspects of the RTC process. Through these variables, it is possible to have a quantified preview for addressing the aforementioned challenges by reducing the time consumed and resources, as well as the risks of creating uncontrollable conflicts and/or co-design contexts where the differences are transformed into barriers that block the creative process. Consequently, this is a relevant novelty to also contribute to advancing co-design.

In addition, we also discussed that challenges for co-design in research processes are (i) evaluating the real impact of co-design (e.g. Slattery *et al.* 2020); and (ii) creating a balance between the scientific rigour and what is produced by the participants through open, bottom-up design that often reflects the urgent needs of a context (e.g.Moser 2016; Slattery *et al.* 2020). RTC offers a system approach to

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embed the discussion of the co-design outcome within a feedback loop that allows testing if the co-design output is effectively responding to the research question. In practical terms, the whole control mechanism serves as a system (i) to evaluate the real impact of co-design for the research needs and objectives; and (ii) to give space and time to the researchers to understand if the co-design output effectively contributes to the creation of scientific evidence. These aspects need to be investigated with in-depth and empirical research to create specific evidence for a systematic application of RTC. However, RTC creates a structured and supported model where co-design as a systematic research approach can address and improve these challenges. In other words, co-design can benefit from the RTC system for addressing common co-design challenges.

Finally, in canonical research, co-design-based processes are discussed as time- and resource-consuming (e.g. Kirk *et al.* 2021). Often the aforementioned challenges become barriers that effectively increase these factors. RTC may help by providing a cognitive and computational model to understand how to optimise the management of those aspects that can increase time and resources in co-design.

4.3. RTC, beneficiaries, actors and non-designers

This paragraph discusses how the RTC model can be used and by whom. Firstly, the RTC model can be used as a strategy for planning how to conduct research that uses co-design with the robustness of the CST variables. The variables of the model simplify the embedding of design thinking – through co-design practices – within a research process. At the same time, the RTC model gives stability and equilibrium to a research process that is driven "through" co-design. Also, the RTC model works as an operating model for doing research in several fields by using co-design as the main engine to balance the research question and the desired answer. In parallel, RTC is a cognitive model of how people may address RTD – with its specific variant of co-design – for research purposes. More specifically, how does RTC work? Each variable of the RTC model is a variable of the research process. Therefore, the variables of the model represent the minimum requirements a research process should cover to adopt an RTC approach. The main beneficiaries of this model are designers and the design researchers – or "designers-researchers" by using Cross' (1999, 2006) terms – that do research by adopting a design thinking approach based on co-design. With this model, they may plan a robust research process with the core of co-design as a creative and open medium of the whole process. Specifically, the main beneficiaries are designers-researchers who have the aim to adopt a research process with co-design practices with a consistent group of non-designers. We argue this model can be useful when the group of co-designers is made up of people with very different backgrounds. Potentially, co-design can be made by all non-designers who use design skills, tools and approaches. How this kind of design knowledge by non-designers may influence the whole research process is the core of the RTC model. It is not uncommon to find groups of co-designers without those people who formally define themselves as designers within a specific design discipline background.

4.3.1. A process for non-designers at the core

By framing RTC, both as a model and as a strategy, we expect to simplify the usage of co-design within research processes that need the contribution of the design

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culture. Traditionally, co-design allows the creation of a design space that lets expert and non-expert designers collaborate. Also, it describes collaborative design processes between researchers from different disciplines, citizens and other individuals who may potentially contribute to the project, and to find research answers. Consequently, co-design deals with the relationship between experts and non-experts, as well as non-designers.

In the introduction paragraphs, we also emphasised that involving non-experts can create a few challenges for applying co-design in formal research frameworks. In summary, we underlined that involving participants from different backgrounds, especially in the case of non-experts, can (i) increase difficulties in creating communication before, during and after the co-design process, with a lack of a common language (Camden *et al.* 2015; Drahota *et al.* 2016; Moser 2016; Slattery *et al.* 2020; Antonini 2021; Vargas *et al.* 2022); (ii) increase the time and effort for involving, effectively engaging and maintaining the interest of the participants (Moser 2016; Slattery *et al.* 2020; Kirk *et al.* 2021); (iii) require the prevention and mitigation of conflicts that generally occur in co-design activities (Slimani *et al.* 2006; Manzini 2014; Pirinen 2016; Zamenopoulos & Alexiou 2018; Andersen & Mosleh 2021) and (iv) create tensions between the scientific rigour and the end-user preferences (Moser 2016; Slattery *et al.* 2020).

These aspects are also risks to successfully using co-design as the main engine for the knowledge production mechanism. Some reflections can be described to mitigate these risks. For instance, regarding communication and language, Pirinen (2016) suggests that designers should adjust their communication according to the organisation where the co-design is applied. And, where the context requires a more formal, scientific approach, the option for "hard" communication should be adopted. Regarding time- and resource-consuming activities, Slattery *et al.* (2020) suggest investing in the right way in co-design by allocating sufficient time and resources, providing pay/reward for participants' time and providing training, if needed. More specifically, for what concern strategies for engaging and maintaining the interest of the participants, Slattery *et al.* (2020) suggest drawing on behavioural insights by considering models such the Fogg's work (Fogg 2019) and the COM-B model (Michie, Van Stralen & West 2011). Regarding conflicts and their mitigation, Andersen & Mosleh (2021) suggest the use of specific tangible artefacts designed to conduct co-design workshops to legitimise conflicts and tensions among stakeholders and consequently create the condition for negotiation. About the balance between the scientific rigour and the open bottom-up design that may merge the urgent actors' needs (Moser 2016), we argue the researcher plays a crucial role. For instance, Blomkamp (2018) by referring to Roggema (2014) and Durose & Richardson (2016) depicts the policy-maker in co-design as a figure that shifts from a "prima donna" role to a facilitating role without losing the scope of gaining scientific evidences from the process. On the contrary, the co-design process creates an addition of knowledge with the contribution of the participants. Similarly, changing the role from director to facilitator and catalyst (Cornwall & Jewkes 1995; Tay *et al.* 2021) by also supporting the participant's expression of creativity (Kirk *et al.* 2021) does not harm the possibility of adopting a scientific approach. Through the researcher in the co-design process, data can be maximised for creating scientific evidence. However, there is a lack of a single model for maximising these data and assessing the co-design impact (Slattery *et al.* 2020) on the whole research process. We suggest taking into account

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the RTC model. It can grasp the participant's needs, through the co-design process and output, without sacrificing the scientific rigour. Indeed, if we interpret preferences, turbulence and participants' needs as conditions of the system to be controlled, we may assume that the RTC control system allows us to manage these turbulences by creating an equilibrium with the research question.

Also, RTC can help in maximising co-design output produced in the collaboration between contextual non-experts, stakeholders and researchers. Indeed, the RTC system allows us to assess if the co-design outputs are consistent, and relevant and do not produce errors for the research question. On the contrary, it will use additional loops to iterate the process and improve the output. Although some authors discussed possible strategies, we noted a fragmented scenario in the literature for addressing these aspects with a single conceptual framework for co-design. The RTC model simplifies this complexity by creating a space where the divergence among people, and their turbulent process significantly contribute to the research process. The RTC theory tries to describe how the complex relationship among all the individuals participating in the design process can contribute to finding a balanced research answer. From a certain perspective, non-designers are the core figure of the RTC model. Indeed, the presence of non-designers in *G(s)* gives the chance to find unexpected design answers. Through the RTC process, these design answers can be tested, verified and eventually validated, but, if they produce an error (the *E(s)* variable), they create a loop that is a benefit both for the whole system and for the actors participating in the process. Therefore, loop by loop the RTC model potentially mitigates the risks that present the co-design process *G(s)* by facilitating the management of the whole research system. In addition, because the RTC model presents computable variables, all these aspects including the unpredictability of the non-designers can be planned. Substantially, the RTC model creates a predictable scenario where the impact of non-designers can be balanced within a computable system according to the RTC system where the research question and answer are assumed as variables that create the expected balance of the whole system.

4.4. Towards co-design as research

RTC, through its model and variables, presents the potential to be visualised and operative. It means to make tangible the process of formalising and developing a research question to find a relevant research answer through co-design, which is a collaborative representation of the contemporary design culture. RTC as a strategy can be applied through the variables, and they are made usable to all those who are engaged in co-design as a way of conducting research. It means formalising the co-design as research. This follows the debate in design research towards the "design as research" perspective. More specifically, the RTC model is intrinsically proposing the "co-design as research," in terms of giving this type of design research the rigours, robustness and practicability as it happened for traditional academic and scientific research disciplines. We argue that just the practice of co-design is not enough to be considered within the "co-design as research" paradigm. At the same time, RTD is not sufficiently representative of the whole complexity of applying participative practices through design as, itself, "design as research." Similarly, the literature debated "research as design" (Jonas 2015 based on Glanville 1997) as "probably the essential mental and social 'mechanism' of

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generating new ideas, the location of abductive reasoning." We thought about this mechanism as more representative of collaborative designing where the collaboration is itself a social mechanism. In the contemporary era, co-design is everywhere and it is largely requested in most of the research processes that need to find innovations. Making these opportunities tangible for every researcher, designer, decision-maker and citizen is what stimulates the research we presented in this article. We feel that RTC is a more empathic model for conducting research through the principles and values of co-design. RTC is research that approaches people's needs and makes them participate, even if not designers, even if not experts. RTC is a tentative theory and model to make even more tangible the concept of doing "co-design as research."

4.4.1. *RTC implications, new insight and future research and practices*

RTC took robustness through the CST. It is something that was searched in previous RTD models, as well as in the pure co-design practice. At the same time, through the basis of the feedback-loop system, we merged RTD and co-design in a unique model that can present a process itself to plan and conduct RTC. It gives RTD a model to refer to, even if peculiarly based on co-design. However, co-design is the real new frontier for design. How is it possible to address complex problems such as those related to climate change and social issues without providing participation sessions and co-design practices? For instance, involving people in research and development, or innovation actions, is becoming a requirement for every programme funded by the European Commission. RTC can support this societal approach by combining science and citizens. Indeed, we suggest RTC as a research practice to be adopted in processes related to citizen science, more largely recognised as an example of open science (Robinson *et al.* 2018). This potentially opens a new area to investigate where co-design, as well as the explorative pragmatism of RTD, plays a crucial, useful and performative role in the research process.

In addition, RTC uses a collaborative model quantifying in an empirical way a co-design research process demonstrating that given a research question, it is possible to calculate the research answer and the relative error between the research question obtained and the prefixed. This allows measuring the error in this control closed-loop system of RTC assuring that the obtained research question is near to the prefixed. This supports optimisations in an empirical way of a co-design process.

This model also can be used to quantify a co-design process that nowadays is not quantifiable (e.g. collaborative action or collaborative co-design task or process). Similarly, the process demonstrates the collaboration of co-design actors who come from different backgrounds in a multidisciplinary approach that empirically demonstrates inclusiveness (e.g. $Co_iCo_j>2$). The predictable features of the RTC model through its specific variables may open new research works, as well as new areas to be investigated, related to the application of this model with AI frameworks. Computing the variables of RTC is something we theorised about in this article. It can be the next step for additional research on the topic. Predicting or controlling through computational help the variables of co-design has a double value (as implications) for future RTD and future design and research practices. The first is reducing the possibility of making errors with participative models

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based on co-design. As a consequence, it improves the possibility of making the funding for research to apply co-design safer by reducing the risk related to the co-design variables. The second is reducing the gap between science and citizen needs. It is in terms of improving the possibility of engaging more and more citizens because the RTC process ensures having a tool to plan, manage and control the multiple variables of these kinds of processes. These two aspects simplify the involvement of non-designers in research processes based on participatory design processes.

Indirectly, this will open new discussions on the role of what are considered as "expert designers." We do not know who will, and if, be considered design-experts, and in which terms. If RTC is applied, future designers will be the ones most likely to adopt and manage this model. In conferences we presented the RTC model as a preview of our original idea, designers were the most responsive to understanding the model and its variable as a research process that lacked their specific design research knowledge. We expect they will use it, reinforcing their research and professional skills and conferring to the related practice the right relevance to make it more academically robust.

5. Conclusion

In conclusion, RTC is a mathematical model of cognitive control for understanding how to co-create knowledge by applying the CST and merging RTD and co-design. RTC may serve as a strategy for those who adopt co-design processes, experiences and knowledge as a medium to gain new ((co)design) knowledge. RTC embeds the participatory paradigm through collaborative design practice and makes the research a collaborative process for learning from all the participants. We argue that RTC can contribute both to the discussion of RTD and co-design by strengthening (co-)design as an independent field of research and offering cybernetically informed methods of inquiry with its form of rigour.

This work tries to contribute to wide aspects of co-design and RTD such as the co-creation of knowledge, research-oriented co-design, diversity and inclusion in co-designing as well as diversity and inclusion in research processes that systematically adopt co-design. Specifically, we designed a model for transforming the RTC idea into an entity to be observed and criticised. Therefore, observing the RTC model we frame contributions both in RTD and co-design field of studies. Specifically, RTC may contribute to confer rigorousness and relevance to RTD processes by introducing the RTC model and its variables. At the same time, by introducing co-design within the RTD discourse, the meanings of "artefacts" and "designers/co-designers" we suggest need a revision. Indeed, co-design and RTC offer different challenges where labels and boundaries may result in insignificant and without providing any real value. RTC may help in reconsidering diversity and inclusion in co-design and collaborative research processes, by introducing variables (such as the PoD) that make the process more careful on these aspects. We described how the RTC model can improve the quality of the whole process by increasing the diversity in the co-design process. The greater the diversity level is, the greater will be the chance to reach the research answer through creative and innovative solutions. RTC is also an auto/self-regulation process where people (co-designers – including non-designers) can learn from each other and improve the quality of the whole system loop by loop. This is the reason why we described RTC

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as an autopoietic learning design system. In parallel, we also open a discussion on some implications the RTC process may offer for envisioning co-design as research. The offered model can simplify these aspects by merging in a unique framework issue such as those concerning open science and citizen science processes.

Finally, the RTC model is described through variables that make it possible to simulate an RTC process. This could bring significant advantages in designing the RTC process by facilitating the identification of expected activities, resources and outcomes, and reducing the general efforts for using co-design. In addition, the possibility of simulating the RTC process is a starting point for identifying AI tools for exploiting co-design in research in multiple ways we have yet to imagine.

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