Between sustainability commitments and anticipated market requirements: Exploring the resilience of the techno-economic innovation paradigm in the midstream of construction research

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Between sustainability commitments and anticipated market requirements. Exploring the resilience of the techno-economic innovation paradigm in the midstream of construction research[1]

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ABSTRACT

This article studies ways of dealing with the tension between a commitment to sustainable and responsible research and anticipated market requirements in the midstream of a research process in architecture and construction. Using a slightly modified version of Socio-Technical Integration Research (STIR), we explored the chances of questioning the primacy of the techno-economic innovation paradigm by deliberately provoking reflections through STIR interactions. Our research underlines the difficulties and limitations of challenging an orientation towards values of efficiency and productivity in favour of social and environmental values in the midstream of the research process and examines *how* the techno-economic innovation paradigm is able to insulate itself against critical questioning. It sheds light at the critical role of the underlying assumption that marketability of prospective outcomes is not one objective amongst others but the precondition for all others and at two argumentative patterns we termed the "lack-of-agency" and the "reconciliation-after-all" pattern.

Keywords: Socio-Technical Integration Research (STIR); Anticipated Market Requirements; Construction Industry; Responsible Research and Innovation (RRI); Constructive Technology Assessment.

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INTRODUCTION: The Need for Responsible Innovation in Architecture and Construction

The construction industry is in need of social, cultural and technological innovation. At present, the industry is a major contributor of greenhouse gas emissions; in 2019, energy-related CO_2 emissions from building operations and construction reached their highest recorded level and accounted for 38 percent of total global energy-related CO_2 emissions (UNEP, 2020). In addition, the industry is responsible for excessive use of raw materials and is a major producer of waste. According to OECD estimates, the global construction sector will more than double from 2017 to 2060 and its use of materials will increase to almost 84 gigatons of construction materials in 2060 (OECD, 2019). Currently, 40 to 50 percent of the non-energy resources extracted for global materials are used for housing, construction and infrastructure (UNEP, 2020); in the European Union, construction and demolition waste accounts for approximately 25-30 percent of the total waste generated. Most of this, including concrete, gypsum, ceramics, metals, plastic, solvents, asbestos and excavated soil, is currently downcycled rather than recycled (UNEP, 2020). Furthermore, even additional construction of more sustainable houses would add to the problems of land use and land sealing.

At the same time, the demand for adequate housing continues to increase worldwide. The UN estimate that the world's human population will grow from 7.7 billion in 2019 to 9.7 billion in 2050 (UN, 2019), with more than two-thirds living in urban areas. Affordable and adequate housing is already seriously lacking. According to UN estimates, 1.8 billion people live in inadequate housing in slums or overcrowded settlements or in a state of homelessness (UN, 2020), exposed to global health crises such as COVID-19 and climate change-induced emergencies. In short, construction faces the double challenge of performing the transition towards a sustainable, net-zero emissions and zero-waste building culture and simultaneously delivering adequate, healthy and equitable housing for a growing world population.

From an economic perspective, construction is suffering mainly from an innovation, profitability and productivity crisis, allegedly due to its notorious aversion to innovation (Roland Berger, 2016; Ribeirinho *et al.*, 2020).

Governments invest their hopes in digital technologies to solve construction's multiple crises and are advocating for building information modelling (BIM) to become standard for public construction projects (Lee & Borrmann, 2020). While some actors voice concerns about job losses, de-skilling, a decline in architectural quality, and economic concentration processes, the dominant view is that digitalisation offers solutions to the housing crisis, the environmental crisis, the economic crises, the productivity crisis, and more recently also the COVID-19 crisis (Braun & Kropp, 2021).

An examination of the socio-technical visions and imaginaries underlying current debates on the digital transformation of architecture and construction (Braun & Kropp, 2021) shows a widespread agreement among industry, policy and civil society actors about the challenges and problems described above as well as nearly universal expectations that digital technologies will offer solutions to all of them. Possible conflicts between technological innovation and other objectives, such as a zero-emissions and zero-waste building culture or a liveable, equitable built environment, are rarely addressed in these discussions; the prevalent assumption is that digital transformation will automatically generate more sustainable, high-quality, socially adequate and acceptable buildings and construction processes. The latter are largely considered by-products of technologically conceived innovation. Borrowing Morozov's (2013) term, solutionism, we can see here a macro-level type of techno-solutionism, a belief that complex social problems can be ascribed to a lack of technological efficiency and process optimisation. Joly and Rip (2012) posit the "cornucopia" conception of technoscience, according to which technoscientific innovations would solve many of humanity's major problems if only sufficient resources could be mobilised to push them forward. Critical research into the interrelations between digitalisation and sustainability, however, has shown that solutionist and cornucopia conceptions do not hold; rebound effects and increased use of energy for servers and ICT operations, among other things, damage the environment to an extent that may outweigh the environmental benefits of digitalisation (Coroamă & Mattern, 2019; Lange *et al.*, 2020). To date, detailed research into the relationships between sustainability and digitalisation in the field of architecture and construction remains scarce (Zhang *et al.*, 2020).

TECHNO-SOLUTIONISM *VERSUS* RRI

There is no problem with technological solutions or technological efficiency per se; it is certainly in the common interest to develop efficient solutions for a sustainable, liveable and equitable built environment. Yet, from a social and environmental justice point of view, problems arise when technological efficiency is defined and measured first and foremost in terms of cost savings and profitability and the values of sustainability, fairness and justice are considered innovative only when they contribute to the former. Under the conditions of global competition, the authority to decide what qualifies as an innovative solution ultimately rests with the market. There is good reason, however, to agree with von Schomberg and Hankins (2019, p. 1) that "market innovations do not automatically deliver on societally desirable objectives". This concern gave rise to the paradigm of "responsible research and innovation" (RRI) (von Schomberg, 2008; Owen *et al.*, 2012; Owen *et al.*, 2013; Burget *et al.*, 2017), defined by von Schomberg as…

> […] a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society). (von Schomberg, 2008, p. 50)

RRI is intended as a strategy to challenge the dominant techno-economic paradigm in research and innovation and counterbalance it with an orientation towards socially desirable objectives and solutions for the grand challenges laid down inter alia in the UN sustainable development goals (SDGs) (von Schomberg & Hankins, 2019). RRI, however, has also been criticised for lack of clarity in its meaning and dimensions and the question of how it should be implemented in practice.[2] Delgado and Åm (2018) state that the notions of societal concerns and public values remain vague. In practice, they note, RRI often comes down to "box-ticking", merely adding a paragraph to a research proposal and a social science and humanities (SSH) scholar to the team, usually last-minute. Another point of criticism concerns the meaning of the word "innovation". Von Schomberg and Blok (2021) argue that in EU innovation policy as well as standard RRI definitions, innovation is effectively equated with marketable technological products as in the definition quoted above ("the innovation process and its marketable products"). More systemic, social, cultural or economic innovations fall beyond the scope of this understanding. As long as innovation is equated with marketable technological products, the authority of the market as supreme decision-making authority will remain unquestioned, and success or failure will inevitably be measured in techno-economic terms. Objectives such as environmental sustainability, inclusion, and a liveable and equitable built environment do not compete on equal footing; they may be by-products but never conflicting objectives. The Socio-Technical Integration Research approach (STIR) (Fisher, 2007; Fisher & Schuurbiers, 2013; Fisher *et al.*, 2015) builds on the core idea of RRI that we can minimise unintended negative and maximise positive impacts of research and development and "nudge their trajectories in various ways toward responsible, desirable futures" (Stilgoe, 2013, p. 14) by adding an approach for midstream modulation of socio-technical research, strengthening reflection on the potential social implications of one's research during the research process itself. STIR has responded to many of the above criticisms, inter alia by providing a clear protocol which allows for in-depth interactions rather than mere box-ticking.

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[2] For an overview see Burget *et al.*, 2017.

In this article, we use an adapted version of STIR to explore whether and to what extent it is possible to render the dominant techno-economic innovation paradigm (with its in-built market orientation) amenable to critical reflection and modulation in the midstream of research processes. To do so, we take our cues from the STIR approach, with its underlying interest in investigating the capacity of academic researchers to more reflexively attend to the social dimensions of their work and to align technoscientific and social considerations during the course of their research. We built on STIR as a rich reservoir of methodological knowledge, practical research experience and empirical findings concerning midstream modulation in interdisciplinary research collaboration. We followed the STIR method, as a semi-structured approach that in its deployment also requires considerable choices and interpretations, quite closely, however with a few adaptions to our case study. The aim of our research was to develop a deeper understanding of how researchers negotiate potential tensions between preset commitments to social and environmental values and values of efficiency, productivity and marketability and what the chances are to deliberately challenge the primacy of the latter through STIR interactions.

In this paper, we present results from two STIR case studies we conducted with researchers from two projects within a large German interdisciplinary research network on computational methods in architecture, engineering and construction. Through interactions with each participant in their everyday work over twelve weeks, we gained insights into the ways they dealt with the techno-economic paradigm. In the vast majority of cases, the STIR approach has already shown itself to be successful in terms of exploring the reasoning for research decisions as well as stimulating reflexive learning, value deliberations and practical adjustments (Schuurbiers, 2011; Lukovics & Fisher, 2017). We argue that in basic academic research, market requirements do not directly impact research but have an indirect impact through *anticipations* of market requirements. However, it is not *the* market that impacts research, or a single way of addressing assumed market requirements, but different ways of anticipating, addressing and approaching market requirements embedded in preset institutional contexts and research practices and different ways of negotiating them in relation to other values. Overall, we found that market requirements are only somewhat malleable and open to reflexive modulation.

In the remainder of this paper, we first introduce the STIR method and our adaptions of it for our specific research context. Subsequently, we present a condensed account of two STIR exercises as well as our findings with regard to anticipating and addressing market requirements and their respective embedding within particular project settings.

SOCIO-TECHNICAL INTEGRATION RESEARCH (STIR)

STIR stands in a long tradition of strategies for integrating societal concerns and considerations into technoscientific research and development, from ethical, legal and social implications (ELSI) and various strands of technology assessment (TA) to RRI (Fisher *et al.*, 2015; Kropp, 2021). Overall, as Job Timmermans concludes, these strategies have shown limited impact on actual developments in research and innovation. "RRI still is chiefly discussed conceptually in terms of frameworks and approaches rather than practically in terms of tools and knowledge transfer" (Timmermans, 2017, p. 20). Some strategies may have been successful in preventing the worst, but there is little indication that they have redirected research and innovation towards more sustainable and socially desirable ends. Integrating societal concerns has proven more difficult than expected, with obstacles and challenges arising from the dominance of the techno-economic innovation paradigm as well as rather formal and last-minute ways of involving SSH scholars and perspectives (Bogner *et al.*, 2015; Mayntz, 2015; Kuzma & Roberts, 2018; Manzeschke & Gransche, 2020; Stubbe, 2020; Strand *et al.*, 2021). STIR tackles these challenges to some degree: it provides a strategy for stimulating reflections on the social contexts of research through regular interactions between an SSH researcher and technoscientific researchers within a particular research setting over a certain period of time. These interactions, which usually take place over twelve weeks, allow for collaborative reflections on the social context and possible implications of the research and, potentially, opportunities for practical adjustments (Fisher *et al.*, 2006; Fisher & Schuurbiers, 2013). However, STIR aims not to radically reorient and change the course of research, but rather to incrementally take greater account of social, ethical and environmental assumptions in the research process wherever possible (Owen *et al.*, 2013).

Through inciting reflections on possible alternative research decisions and practices in the interaction between technology researchers and SSH researchers, STIR appears suited to motivate the contemplation of market requirements, their influence on the research process and the relationship between techno-economic imperatives and competing objectives of delivering socially desirable outcomes.

Thus, STIR is a form of what Konrad *et al.* (2017) term "constructive technology assessment" in that it...

> ...aims to mobilize insights on co-evolutionary dynamics of science, technology and society for anticipating and assessing technologies, rather than being predominantly concerned with assessing societal impacts of a quasi-given technology. In addition, it shifts the focus from policy advice to (soft) intervention in the ongoing construction and societal embedding of technologies. (Konrad *et al.*, 2017, p. 15)

Through documenting the engagement of technoscientific researchers with the socio-technical context of the work in real-time collaborative reflection about possible implications of their work, it is possible to analyse those co-evolutionary dynamics on a micro level and observe how the ongoing construction of technologies might change through such reflection (Schuurbiers, 2011).

STIR focuses on midstream modulation (MM) (Fisher *et al.*, 2006; Fisher *et al.*, 2015), seeking to distribute "responsibility *throughout* the innovation enterprise, locating it even at the level of scientific research practices" (Fisher & Rip, 2013, p. 175). MM denotes incremental processes of altering research and development practices and decision-making in response to social constraints as well as social values, considerations and influences more generally (Fisher *et al.*, 2006; Fisher & Schuurbiers, 2013; Owen *et al.*, 2013). Importantly, modulation occurs in any case; there is no unmodulated research or innovation process. The critical questions are whether modulation occurs consciously and whether it is oriented towards sustainability, equity and inclusion. STIR aims at MM as a way of enhancing the responsive capacity of researchers to consider the social and environmental contexts and implications of their work and, possibly, align research and innovation agendas more closely with public values and desirable futures (Fisher & Schuurbiers, 2013). It has been found to support two modes of reflexive learning: first-order and second-order. First-order reflexive learning focuses on reflecting and improving research decisions in relation to the framework of objectives, assumptions, background theories and values underlying the research, while second-order reflexive learning subjects the given normative, epistemological and institutional framework to critical inspection and reflection which then extend to the research culture and its methodological, epistemological, ontological and socio-ethical premises (Schuurbiers, 2011, p. 772).

We built on this approach but also interpreted it slightly differently in that every now and then, we explicitly raised questions regarding the social and environmental impacts of the research. We consider this appropriate since, in this case, the research network had already made a commitment to these goals, hence we did not bring them in from outside. By socio-technically integrating, jointly situating and critically interrogating the guiding research assumptions and practices in the sessions, our aims were to promote consideration of social, ethical and environmental aspects and impacts and to collectively explore possibilities for more than incremental adaptation to sustainability challenges.

STIR can result in first- and second-order reflexive learning through two modes of interaction, termed STIR 1.0 and STIR 2.0, between SSH researchers and those with science-technology backgrounds. STIR 1.0 has a more *reconstructive* character; it aims to identify constraints and requirements, interests and expectations (such as the expectation to deliver marketable products) on the level of the research practices, institutions, or society at large, constituting the cultural background to the research process. STIR 1.0 probes and assesses the capacity of midstream agents to modulate their practices and research trajectories under given conditions (Fisher *et al.*, 2016). Therefore, STIR 1.0 can have an intervention-oriented and transformative effect on research practices and capacities. STIR 2.0 has a more explicitly *transformative* aspiration, attempting to deliberately modulate the research process by calling attention to social and ethical impacts and, with our adaptation of STIR, questioning given assumptions (Kropp, 2021). "As a research program, STIR 1.0 probes the conditions and capacities for broadening socio-technical integration while, as an intervention, STIR 2.0 attempts to exercise these capacities deliberatively" (Fisher *et al.*, 2015). Insofar as we deliberately invited the techno-scientific researchers to reflect upon the impacts of their research with regard to substantive values the research network had committed itself to, we indeed practiced a version of STIR 2.0. Yet, it was a version of STIR 2.0 in which the SSH researcher referred to values that had already been inscribed in the research framework; thus, the SSH researcher rather recalled these values and commitments in the interaction rather than newly introducing them.

STIR scholars have distinguished three types of MM, referring to different levels of reflecting and modifying research activities: *de facto*, reflexive and deliberate modulation (Flipse *et al.*, 2013). In *de facto modulation*, the SSH researcher recognises so-called decision modulators that shape the research process. Such modulators can encompass a variety of cognitive assumptions and social or material framework conditions that inform the research process, including guiding assumptions and expectations posed by the particular research settings or the institutional context. To which extent these may determine the research, and to which extent they can be modified, are empirical questions that cannot be answered in advance. In *reflexive modulation,* the participants become aware of the ways in which assumptions and expectations influence the actual research process, thereby making it possible to render them negotiable and modifiable. In *deliberate modulation*, researchers actively and deliberately integrate certain *de facto* modulations in their decision-making. (Fisher & Mahajan, 2006; Flipse *et al.*, 2013; Kropp, 2021). Following our adapted STIR approach, in *deliberate modulation,* we aimed for the researchers to not only deliberately integrate considerations about *de facto* modulations, but to question some and consider others addressed by the SSH researcher. Deliberate modulation is therefore of particular importance for responsible innovation. The three types of modulation also form conceptual devices for interpreting the data acquired through the STIR process (Flipse & van de Loo, 2018).

Based on our observations using the STIR protocol (see Fig. 2), we decided to expand the process by one step; we actively questioned and challenged guiding assumptions (such as techno-economic orientations) and asked participants to reflect on them. The participants were then invited to argue whether it was possible to more strongly orient their work towards social, ethical and environmental objectives beyond the dominant techno-economic paradigm. Our intention was to determine whether we could ascertain the participants' views on the potential of various modes of changing direction. The participants' accounts of the constraints reducing the possibilities of adjusting their work made it possible to understand the role of anticipated market requirements for research activities in the midstream.

STIR IN ARCHITECTURE AND CIVIL ENGINEERING

Our STIR exercises took place within an ongoing interdisciplinary research network in architecture and engineering. SSH researchers were included from the beginning and are contributing to the research.

Within this context, we collaborated with one researcher[3] from engineering (Researcher E) and one from architecture (Researcher A) in two separate STIR exercises. Both researchers assumed central roles within their respective projects.[4] During the two STIR periods, SSH Researcher I (for socio-technical integration) used so-called decision protocols (Fisher, 2007) and conducted twelve guideline-based semi-structured conversations with both researchers to jointly explore upcoming research decisions in terms of general objectives, options, guiding assumptions, possible alternatives and expected outcomes (see Figure 1). The decision protocol allows the participants to systematically address and reflect on their current research decisions against the background of the assumptions considered relevant and the possible courses of action. In this sense, the decision protocol serves as a guideline for these in-depth, problem-centred conversations. Through regular interaction and dialogue over several months, it was possible to track changes in the technology researcher's position and address recurring assumptions and themes in greater depth.

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[3] STIR is not necessarily limited to interactions with individual researchers; however, due to the framework of the research context, our cooperation had to be closely coordinated in advance. In this study, we therefore limited STIR to individual interactions.

[4] For reasons of anonymity, we use the gender-neutral pronouns they/them/their when referring to the researchers.

Figure 1: STIR decision protocol as basis for semi-structured conversations

Opportunity Describe a problem, opportunity or decision you are facing.	Considerations What should you consider in responding to the opportunity?
What do you anticipate you will do, why, and who might care? Outcomes	What courses of action are available to you for responding? Alternatives

Source: Phelps & Fisher, 2011; authors' representation (Frost *et al.*, 2022). For the decision model underlying the decision protocol, see Fisher, 2007.

At the beginning and end of each STIR period, we conducted longer interviews on research goals, horizons and expected results. For the analysis, the decision protocol-based conversations were treated as semi-structured interviews. Researcher I also documented ethnographic observations during project meetings and experiments.[5] The research thus comprises 28 interviews as well as observations of seven meetings and experiments. All conversations were audio recorded and transcribed; the transcriptions, together with field notes and STIR decision protocols, were coded using MAXQDA. After open and selective coding, a case narrative was written and case information and different categories were cross-compared. The interviews with Researcher E were translated from German to English by Researcher I, and the translation was presented to Researcher E to confirm its accuracy.

We here present a condensed account of the STIR processes and their outcomes with regard to reflections on anticipated market requirements and their impact on the research process. Our account is based on a selection of significant passages from the STIR transcripts. Importantly, the fragments of socio-technical interactions presented here do not represent the entire range of themes and reflections within our STIR processes. Since the focus is on the role of anticipated market and industry requirements, we selected only those sequences that refer to this aspect.

Set goals: Sustainability, efficiency, design freedom

In the research projects studied, problem descriptions and objectives were not determined by the individual researchers but were provided by the research settings specified in the research network. Moreover, both the interviews and Researcher I's observations during the course of the STIR exercises documented that the individual projects stood in the tradition of their respective research institutions and were shaped by previous research and innovation activities.

Department E's long-standing reputation for the development of lightweight concrete is reflected in the department's expertise, experiential knowledge, network of research partners, and technologies employed. It is of vital importance to the department to minimise resource consumption for building construction, as evidenced by publications, public lectures, and previous projects by department members. At the same time, the agenda of the overall research network emphasises the need to build more and faster to meet global needs. Material savings through lightweight construction are intended to (at least partially) reconcile these opposing challenges, to which Researcher E frequently referred. The development of lightweight building components reflects the dual objectives of reducing building mass and reducing CO_2 emissions in the production process. Moreover, prefabrication instead of on-site processing, as Researcher E explained, allows for components to be produced at higher speed, "because, of course, it's an industrial process and it thrives on you getting your products out quickly".

For Researcher E, developing resource-saving building components is a way to serve environmental, social and economic needs simultaneously:

> …because we have to build more and more quickly for the people who will soon all want to move out of their homes. […] And […], look here, this is a beam […] that has the same load-bearing capacity but a reduced weight. In the end, that is always a quality criterion for our own work to say we can do the same thing as is currently possible, but with less weight. That is always the primary guideline.

In Department A, as Researcher A pointed out, environmental concerns such as the excessive consumption of resources and the simultaneously growing demand for built-up space also play an important role. In addition, the aim is to increase design freedom and harness the full potential of computational technologies to create innovative and flexible building systems that would contribute to a more sustainable and liveable building culture. Researcher A consistently explained his research decisions in terms of creating new design options.

The issue of environmental sustainability also figured prominently in Researcher A's statements and is reflected in the research focus on timber buildings; timber is considered a renewable material which also stores CO_2. Researcher A explained that combining digital design and robotic manufacturing could increase design options as well as process efficiency and "make it high speed, high detail". Given these features, they expected resultant new building systems to be characterised by high flexibility and building longevity.

Department A draws on a history of material development, computer-based design and robotic manufacturing, as reflected in the technologies used and associated expertise. Researcher A mentioned numerous intensive, worldwide collaborations with other researchers in these fields; the department also maintains close contacts with the domestic construction industry and policy-makers, whose expectations were very familiar to the researcher.

As for the specifications set down by the overall research network, these refer explicitly to the global environmental crisis and the housing crisis in the context of global population growth. In light of these challenges, the network's overall objective is to promote digital technologies that advance a sustainable building culture and contribute to a high-quality, liveable and sustainable built environment. The overarching research framework includes the commitment to reduce CO_2 emissions and waste production as well as increase the productivity of building construction. Social and environmental goals thus stand side by side with techno-economic goals. Interdisciplinary research projects within the network have taken up this framework to define their specific research strategies and objectives, including resource-minimizing work with concrete and timber. These strategies and objectives were fixed and not to be implemented at the discretion of the individual researchers.

During the STIR exercises, Researchers A and E repeatedly expressed that they shared their departments' and the network's professed orientation towards social and environmental values. Alongside these values, and also in line with the network's overall objectives, process and system optimisation (particularly in terms of time efficiency) was another top priority for them. As these values can come into conflict with one another, they became a matter for reflexive modulation.

Disruptive change, incremental innovation, and the metrics of achievement

While the two projects started from similar problem descriptions and objectives, the researchers encountered different challenges to industry adoption of their proposed outcomes. Concrete is one of the most extensively used building materials in the world (Gagg, 2014), and the concrete construction industry is well established and stable. In contrast, timber buildings are on the rise but still make up only a small portion of buildings; the timber-building industry is comparatively small. Modular construction is popular in building with timber; it allows for relatively cost- and time-efficient mass production of building components but imposes considerable limits on form-finding and architectural design options.

In our case study, the researchers took the structures of the respective industries into account. Meeting market requirements was an indispensable prerequisite for them to implement a more sustainable construction method that would gain ground beyond academia. The values of productivity, profitability and marketability therefore assumed first priority as they would determine whether the researchers' developments would eventually succeed. Both researchers anticipated and addressed these requirements but did so in differing ways, with one envisioning the diffusion of the prospective product within the given industry structure and the other proposing a sectoral change.

In architecture, the focus was on changing the building culture by disseminating new timber-building technologies that would disrupt the industry. As Researcher A explained:

> I would want it to be considered normal to build exclusively out of timber. […]. Whereas like in industry […] you would start designing something and then at some point somebody says, well, what's it made out of? Concrete or steel? And often timber [is] just fully left off the board. So, I think a positive change to the building culture would be for people to say to me, assuming it was made out of wood and then ask, "is it made out of wood or something else", you know, or at the very least for wood to be on this list, you know, like "Is it wood, concrete or steel?" Like three options rather than just two.

In engineering, the aim was to develop more sustainable but also techno-economically efficient solutions that would thus be attractive to the established industry. In this way, the outcomes of their research would make the industry more sustainable. For Researcher E, the focus was not on disruptive change but on incremental innovation:

> Therefore, our first goal is to make it [the building components] lighter. Because it is simply necessary, it is socially necessary. And after that, of course, it follows relatively quickly that people also have to apply it. And that means that it has to be easy to do, that I can perhaps even say that I don't have to completely change the industrial processes as they exist now. But I offer an addition. I offer a way to apply it differently for a better result.

In their research decisions, the two researchers thus adopted different strategies for dealing with the presumed market and industry requirements. Techno-economic criteria played a major role in the research decisions taken in Department E. Here, a key question was how to achieve material efficiency that would translate into time and cost efficiency. The technology under development had to have a competitive advantage over others in techno-economic terms; otherwise, it would assumedly have no chance of being adopted. Thus, the goal for Researcher E had to be "that we say we are better, we are lighter and cheaper. And faster in the end". The strategy was not to develop innovations for an industry that might have to adapt to future policy shifts. As Researcher E stated:

> […] the moment a carbon tax comes in, you've won with something like that. If you can then really say, we'll do the same, but [with] 50 percent, 60 percent less material.

In Research Project A, on the other hand, the strategy was to highlight the economic advantages of the novel research outcomes. These outcomes, the researcher explained, had to be comprehensible to industry actors and connect to existing knowledge, values and ideas about architecture and construction processes. Researcher A explained the idea by referring to reactions towards one of their earlier prototypes:

> It could have been a much more designed object, as this original version was. And that was sadly one of the feedbacks that we received when we showed this around, that it looks great, but it makes me think that it is a designed object, not that it is an example of a multi-storey building system.

Both researchers anticipated how the industries would respond to their work. In one respect, the researchers took a strategic stance towards the techno-economic imperative of increasing productivity, profitability and marketability; meeting this condition was seen as a means to the actual end, namely achieving a better, more sustainable building culture. In another respect, we see that, once the techno-economic imperative is accepted, it tends to outweigh all other ends and values and to define the very standards for measuring success and achievement. Researcher A, perhaps unwittingly, illustrated this mechanism:

> And if we can even target five percent of buildings, it's a 13 trillion euros per year market. OK, and even five percent of 13 trillion is great. So [I'm] cool with that number.

Making money was certainly not the purpose of their research; advancing sustainability and freedom of design was. Still, achievement and success were gauged in terms of money. Why is this? Perhaps we encounter a more fundamental problem here that occurs when qualitative goods, such as environmental sustainability or freedom of design, compete with quantifiable ones, such as market share and market volume. Before relative weights can be assigned to qualitative and quantitative goods, a common standard must render them comparable. A common solution is to translate quality into quantity – social, cultural or environmental values into economic ones. In this case, the researcher sought to express the importance and desirability of non-quantifiable values by translating them into economic ones. Such economic valuation of environmental principles is not an individual process derived from external constraints but a long-established routine relying on social agreements based on valuations (Prior, 1998; Asdal, 2015). Yet, strictly speaking, this translation is logically impossible; quality *is not* quantity, and to quantify qualitative goods actually means to negate the difference. Qualitative goods are then taken into account only if they are valuated or "co-modified" (Asdal, 2015, p. 169-170) in relation to quantifiable ones.

For this reason, we would argue, social, cultural and environmental values literally cannot compete with economic ones. In the tradition of seeking optimal resource allocation, however, only the quantified is governable; accordingly, this translation is a routine technique in innovation processes.

On the whole, both researchers taking part in our STIR exercises took for granted that market and industry requirements could not be suspended or circumvented. In STIR terminology, these requirements were considered to be beyond the scope of MM and thus beyond the reach of collaborative modifications — a finding that points to the need for RRI activities on striving for an upstream level of innovation policy by, for example, providing effective incentives (Gurzawska *et al.*, 2017; Manzeschke & Gransche, 2020).

In the following section, we discuss the extent to which STIR has proven suitable for rendering conflicting research objectives – in particular techno-economic *versus* social, cultural or environmental objectives – amenable to reflexive modulation. We present two instances in which STIR 2.0 was practised to challenge the primacy of techno-economic objectives in research.

ADDRESSING CONFLICTING OBJECTIVES – "There is little we can do to affect their economics"

Let us consider conflicting research goals as they occurred in the course of STIR interactions in Project A. Researchers I and A were discussing the possibility of restricting design options to those that meet the so-called Goldilocks density – dense enough but not too high – to save land and encourage the liveability and affordability of cities. While developing technologies to meet the Goldilocks density might be a socially desirable goal, Researcher A explained, it would conflict with the goals of increasing freedom of design, demonstrating economic benefits, and presenting design options for timber construction – that is, goals that had been fixed in the overall framework for the research project:

> So, if we had talked about restrictions like the seven-storey thing, it would have reduced our potential for impact. […] There exist opinions that this Goldilocks density is correct for urban life — I don't know if I hundred percent agree with them — but I think they're quite nice. But we would not want to restrict anything we are designing or anything we are building to that. I think that the more types of buildings and the more heights and sizes and shapes of buildings that are possible, the better. It supports the thesis which is expanding what is possible within timber building construction.

Here, the goal of expanding design options for timber buildings and demonstrating them was given priority over promoting buildings that promise socially desirable urban density. Decisions regarding building height and density would be left to future construction actors such as clients or planners; the researcher would not need to determine these parameters in their own developments. In this case, the conflict between different research objectives – expanding design options and demonstrating the varietal range of timber buildings on one hand and contributing to a more liveable and sustainable spatial order on the other – was managed by dividing the responsibility between the innovator (for generating design options) and future construction actors (for deciding which ones to realise). In short, we could say that reorienting the research towards more desirable social outcomes was discarded in favour of relying on established but as yet unsuccessful downstream modulation via regulations and market mechanisms: "*De facto* policies of hoping for the best and letting the future take care of itself" (Stilgoe, 2013, p. xv) are widespread, STIR interactions notwithstanding.

Another conflict emerged between the objective of developing more durable and therefore sustainable buildings on one hand and optimizing process efficiency on the other. For Researcher A, developing efficient design and production methods as well as durable, hence sustainable buildings were a major objective around which all research decisions were oriented. Process efficiency and building longevity, however, can collide when increased process efficiency makes it profitable for investors to demolish existing buildings and quickly build new ones in large numbers. This would be a case of an unintended rebound effect: an individual new building might be environmentally sound, but economic incentives can lead to increased construction activities that outweigh the benefits of sustainable building.

Researcher A was aware of this potential collision of goals but saw no way to address it in their work as "there is little we can do to affect their economics". From their point of view, it was beyond the scope of their research, and consequently the need to assign priority to one of these conflicting objectives did not arise. While this merely eschewed the conflict, Researcher A resorted to another solution, concluding that market mechanisms may drive the premature demolition of buildings and that, given these mechanisms, increased process efficiency could even reinforce this tendency:

> I would say that many of the buildings that are considered thrown away or that are built […] for 20-year lifespans and destroyed after five are buildings of lower quality. And by quality, I mean not only that their materials are cheap, but their design is simple.

Another outcome, though – increased design quality – would outweigh that adverse effect. In this case, Researcher A chose to reduce the potential for unintended effects of innovation and resolved the tension between the two objectives in a way that was compatible with the general framework settings outlined above. These stipulate that increasing building longevity and process efficiency and design options are compatible. Within this framework, the techno-economic innovation paradigm remains unquestioned; conflicts between the techno-economic goals of increasing time and cost efficiency and the social, cultural and environmental goals of a sustainable, liveable built environment cannot be addressed as long as achieving the former is taken as a precondition for the latter. Consequently, the researcher's scope for responsible decision-making is seen as confined by the laws of the market; they are aware of these constraints but do not see a way or need to modulate them. In this case, the adapted STIR approach with its transformative aspiration did not stimulate critical debate on the primacy of the techno-economic paradigm, its influence on research and possible undesired effects of that research.

Is promoting social justice feasible?

The question of undesired side effects also arose in Research Project E. During STIR interviews, Researchers I and E discussed the question of whether new methods to reduce material consumption in construction might reinforce the trend to build bigger and more. In a global context, Researcher E argued, this raises questions of social justice:

> Because the question is whether we are allowed to emit more CO_2 now, for example, just because we can, because we have the space, *de facto*, we have the space for it, we can emit more CO_2 than in New Delhi when new buildings are being constructed there, because it is simply less space per capita available. It's a question of justice that comes up again and again.

A responsible decision, the researcher argued, would be to refrain from building in many places in which one could. Yet, again, they saw no way of incorporating these considerations into their everyday work; the issue seemed to be beyond the scope of the micro-decisions made in research practices:

> The problem is not that I don't like to acknowledge that it would make moral sense for us to take less so that others can get more first, until a point where we say, okay, now we're kind of on the same level. I would regard the problem as one of feasibility.

The researcher was aware that their research might have the unintended effect of further fuelling construction activities and, in turn, land use and CO_2 emissions, thereby possibly exacerbating existing global justice problems. Still, it did not seem feasible for affluent countries to reduce construction activities and CO_2 emissions for the benefit of those in other countries. In any case, the researcher did not consider it necessary to deliberate the question in their actual research; they kept instead to the more obvious and realistic option of making construction more material-, cost- and time-efficient. While it is certainly debatable to what extent such a highly complex, global problem can be taken into account in academic research, it was striking that there was no further attempt to discuss possible ways out of this dilemma. Suggestions by Researcher I to think, for example, about ways of developing a building system for smaller layouts were not taken further.

These interactions illustrate that STIR can indeed inspire reflections on responsible research; the participants considered the social and environmental implications and the side effects of their work. Yet these considerations remained somewhat abstract in terms of effects attributable to market imperatives such as increasing profits by building more in less time. They did not know how to integrate these aspects into their everyday work as they seemed unmanageable, far removed from their own sphere of influence and beyond their perceived responsibilities. When social and environmental objectives such as building longevity, flexibility of use, and reducing CO_2 emissions conflicted with techno-economic goals, the latter always prevailed, less due to conscious decision-making and priority-setting than to the underlying assumption that there was no way around market mechanisms and that only those research outcomes that meet private-sector economic requirements could have any impact. In other words, research outcomes could translate into successful innovations only if they were to provide a demonstrable techno-economic benefit proven in the market. Through our adaption of STIR 2.0, which challenged the assumption that downstream dynamics could not be influenced by midstream activities, it became clear that the participants found it both unrealistic and inadvisable to neglect market requirements in favour of building durable structures and promoting environmental and social justice.

QUESTIONING ASSUMPTIONS IN DECISION-MAKING

Ideally, STIR opens up spaces for second-order reflexive learning processes, that is, reflections on the possible social implications of one's research, even if these might challenge the underlying assumptions and expectations of the research settings or the societal context. In the following sections, we analyse instances of second-order reflexive learning in the context of STIR 2.0, which, as described above, we sought to achieve by critically questioning the primacy of the techno-economic innovation paradigm in reaction to the explicit sustainability commitments made by the overall research network. In the first example, Researcher I questioned the concept of co-design, which was key to the work of Researcher A. In the second example, the concept of democratic digitalisation discussed during STIR sessions modulated the assumptions underlying Researcher E's decision-making process. While the first example points to possible barriers to deliberate modulation in terms of responsible innovation, the second shows how the integration of socio-ethical concepts in the decision-making process can succeed.

STIRring the concept of co-design

Researcher A's work on a multi-agent system for computational design of multi-storey timber buildings was strongly influenced by the research network's understanding of co-design. Simply put, co-design denotes an approach for integrating design and construction processes through computer-based feedback loops. It entails multidisciplinary collaboration among construction professionals from various fields such as architecture, structural design, building physics and lifecycle assessment.

Integrating the needs or expectations of further stakeholders was not a constitutive element of Researcher A's co-design concept. The focus was on integrating technical and environmental requirements and related professional expertise, not because the requirements of residents or stakeholders were deemed irrelevant but because they seemed incompatible with the computer-based, numerical approach that had been chosen. As Researcher A explained:

> So, if somebody else would want to use this similar approach, but then maybe also integrate [....] retail consultant knowledge or something like this, then, you're right, they would not be able to use this tool. If it is possible that they would, why would they even want to? So, I think this brings up a harder question about what to try to automate, because at least from my understanding and my experience within architecture for the last decade, the key data-driven slash numerical players in every project are some amount of structural designer, the architect and the material use [referring to lifecycle assessment]. So that is why I do think that the reason we've included building physics into this as well is because it is a highly numerical, data-based field.

Non-numerical matters of concern escaped the technologies already developed and could not be integrated into the new approach. From the perspective of science and technology studies (STS) (Jasanoff, 2004), we can see this as a case of co-production in the sense that the technological approach co-defined the social and cultural values at stake – technical and environmental quality, not stakeholder or community participation – and co-shaped the social practices of planning, constructing and inhabiting buildings. Schikowitz (2020, p. 222) points out that the production of societally relevant knowledge to which researchers aspire must make research "do-able by aligning diverging commitments, concerns, requirements and practices", especially in situations of conflicting objectives. In this case, the alignment seems to be accomplished through the reliance of researchers on quantitative and numerical approaches.

On one occasion, a discussion arose between the social scientist and the architectural researcher on whether to expand the co-design method to include community or stakeholder perspectives through defined interfaces. Researcher A argued that these matters were important but should be left to the planning architect:

> [This] is a thing that the architect is supposed to do, to kind of handle how the product or how the building will affect the community. And I think that this continues to be an architect-specific task and not a community-based task. So, the community will express its views or desires, and it is up to the architect to distil them and implement them within this co-design. Within my understanding of design, the vox populi will still be heard, but it will be heard through the filter of the architect. And that is how it will affect the design. I don't think it affects the co-design directly.

The researcher here evokes the notion of the architect as the mastermind of the construction process who integrates all requirements. From their perspective, freedom means first and foremost freedom of architectural design. In terms of co-production, one could say that a technological approach oriented towards aspects and activities that can be represented on a numerical basis was perceived as compatible with the objectives of expanding architectural design options and increasing system efficiency. The linkage between these elements proved quite stable throughout the STIR process and was not challenged by deliberate reflection. Integrating aspects of non-numerically representable quality through participatory design options, under these premises, appeared unfeasible. Using Schikowitz's concept of the production of societally relevant knowledge, we can understand this episode as an effort by the researcher to make the different commitments, concerns, demands and practices do-able by resorting to the quantitative methods and goals available to them (Schikowitz, 2020).

"Good" digitalisation: "You don't have to imitate everything"

In Project E, STIR interactions prompted discussions on the social dimensions of the research on a rather fundamental level. Arguably, such discussions can influence research decisions and in this sense lead to deliberate modulation. One such instance referred to a conversation on "good" digitalisation and the framing of a research decision by Researcher E in terms of social implications.

As mentioned above, Project E was working on a cyber-physical system for producing material-saving building components. During the STIR process, a project decision was taken to employ a modular system in order to enable separate instalment of individual pieces of equipment such as a laser scanner or an automated extruder. This would allow users to automatize some components of the production process while keeping the manual nature of other parts in place for the time being. Researcher E explained that a modular system would lower the cost of investment and give users more flexibility:

> The question is: Do you have to buy the entire system? […] Because that's the problem, then you have another juggernaut, and either you have the thing or you don't. But if I say that the whole system can also be 3, 4, 5, 6 individual modules, which I then can possibly link with each other, then the hurdle of getting a single module and achieving an improvement is lower, and probably you can then also optimise each module individually.

The topic of user flexibility and the question of when and what to automate harked back to a previous remark by the researcher and a STIR discussion on "good" digitalisation:

> That's why I think it's good that we have this discussion [about 'good' digitalisation] in our [research network], that we can also ask ourselves, do we have to go in this direction now and in which direction do you start and where does digitalisation really bring added value?

Researcher E added that "good" digitalisation must be "[distinguished] from a capitalist or capitalistically-shaped digitalisation [and] from a dictatorial or dictatorship-shaped digitalisation", referring to digital surveillance technologies, which the researcher considered problematic from a democratic point of view. In the context of this conversation, Researchers I and E discussed what would constitute "good" digitalisation, when automation would make sense from a more-than-techno-economic point of view, what good work in cyber-physical production systems could mean and what ethical and social problems could arise from uncontrolled digitalisation. They agreed that not everything should be digitalised or automated:

> Researcher E: I think you can do it right and you can do it wrong. [...] But in my opinion you don't have to copy these things [that are done in China or the US], but you can also say: How should a democracy actually look like, how should digitalisation […] actually look like in an open and free democracy? [...] But you have to ask yourself, what does digitalisation look like in our country? So how would it work in our culture? Researcher I: Do we want it, in what form do we want it? For what purpose? Researcher E: Yes, exactly, like that, and then you don't have to imitate everything, you don't have to [digitalise] everything.

We observe here a kind of reflexive learning for socially robust innovations and, as such, a case of deliberate modulation emerging from conversations about good, democratically desirable digitalisation that led to the decision for a modular system and were reflected in the accompanying rationale. At the same time, the rationale for the modular approach conflated the question of what made sense for society with the question of what made sense for businesses; democratic, socially desirable digitalisation was represented in economic terms, and again we see that social considerations can be integrated when they appear not opposed to, but compatible with market requirements.

CONCLUSION

Within the techno-economic innovation paradigm, socially and environmentally responsible outcomes are assumed to follow from techno-economic innovation. In this paper we have explored the chances and limitations of socio-technical integration when it comes to challenging the primacy of that paradigm in academic research.

In particular, our question was what the chances and limitations are of provoking reflections on possible conflicts between values of efficiency and productivity and social and environmental values in the research process, thus challenging the primacy of the techno-economic innovation paradigm. To do so, we applied a slightly modified version of STIR, STIR 2.0 as we put it, by critically questioning assumptions and objectives that conflict with social and environmental research goals. The STIR processes we conducted within two projects have shown the techno-economic innovation paradigm to be rather resilient towards deliberate modulation. Questioning such fundamental orientations, we conclude, does not suffice to mitigate the influence of market imperatives in the research process; midstream modulation is not sufficient to put other concerns on the agenda vis-à-vis these external expectations which are deeply rooted in and incentivised by scientific institutions. Obviously, a truly multi-level systemic change also requires upstream and downstream modulation and therefore requires broader governance of knowledge production involving governmental bodies, industrial and civil society actors to address market deficits (von Schomberg & Hankins, 2019, p. 2).

While these findings will not come as a complete surprise to Socio-Technical Integration researchers, this article has shown *how* midstream actors deal with the tension between market imperatives and techno-economic values on the one hand and social and environmental values and commitments on the other. In particular, we observed certain patterns of how researchers sought to negotiate these tensions.

We can recognise one underlying assumption at work and two ways of dealing with situations of tension in which the techno-economic paradigm is challenged. The tacit assumption underlying the overall research framework as well as the individual projects was that marketability of prospective outcomes was not one objective amongst others but the precondition for all others. According to this assumption, marketability is not everything, but without it, everything would be nothing, given that sustainable, socially and aesthetically attractive products can only make a difference if adopted by the market. Therefore, societally desirable goals and techno-economic ones did not compete on equal footing; in case of conflict, the prioritisation of the former was always pre-determined. This assumption, which characterises the techno-economic innovation paradigm in general (Callon, 2002), could not be fundamentally challenged through our STIR exercises.

The participants did reflect upon the social implications of their work, including possibly undesirable effects arising from market mechanisms (incentive to demolition, aggravating global injustice). In some instances, modifications of specific research concepts (co-design) or strategies (systemic or modular automation) in order to integrate social concerns were considered. In these situations, the possibility of conflicting goals emerged, yet was resolved through two recurring argumentative patterns which we call the *lack-of-agency* and the *reconciliation-after-all* patterns. By "lack of agency" we mean that a particular course of action was considered unfeasible on technical and/or economic grounds and deemed beyond the sphere of influence of the individual researcher (e.g. for or against Goldilocks density, building demolition, increased construction activity). Another way of managing such conflicts was to point out how the research would contribute to reconciling them in the future "after all" (e.g. building quality superior to that of those demolished). Deliberate modulation in favour of societal concerns thus occurred, but only when it aligned with market requirements. As a result, the chances of critically challenging the above-mentioned tacit assumption and initiate substantive changes through social considerations proved to be limited. Nevertheless, our STIR 2.0 exercises have led to a better understanding of how anticipated downstream in form of market requirements is stabilised in research practices. We were able to observe how co-production of technological approaches co-defined the social and cultural values at stake and co-shaped the social practices of research. At the same time, the relevance of making technology research do-able by aligning diverging commitments, concerns, requirements and practices became quite clear.

These findings point to a lack of alternatives to market-driven diffusion of research outcomes, making it difficult for researchers to visualise success and achievement independent of market requirements. If the aspiration of research is change through adaptation of research results in a particular field, researchers appear to perceive the anticipated downstream as being of enormous importance. Every development, no matter how socially desirable and ecologically sustainable, must then prove itself capable of competing according to the logic of the field. This indicates that an upstream agenda alone, even one with an explicit normative social and environmental commitment as in these cases, can only succeed alongside critical consideration of the downstream. Only by simultaneously considering and shaping all moments of the innovation process can more socially responsible and sustainable development pathways be conceived. Policy-derived, subsidised niches for sustainable innovations, such as those Germany has created for renewable energies, are promising, but they are as yet scarce in the construction sector. Thus, in order to reorient research in digital architecture and construction away from techno-economic imperatives, socio-technical integration would have to confront them at all levels:

midstream, upstream and downstream (Fisher & Schuurbiers, 2013; cf. Yaghmaei & van de Poel, 2021). Creating niches as incubation rooms for radical novelties, locations for learning processes and space to build supportive social networks (Geels, 2002, p. 1261) may counteract the recurring "lack-of-agency" and "reconciliation-after-all" argumentative patterns in research practice. Even if niches cannot escape techno-economic imperatives, they are to a certain extent protected spaces for experimentation that have a more open character of configurability and do not require an immediate connection to given regimes such as market requirements in order to innovate.

Let us again emphasise that the problem is not with technological efficiency as such; difficulties arise, however, when it is defined and measured solely in economic terms, with social and environmental values only considered to the extent that they can be translated into the former. STIR and our approach of STIR 2.0 can evidently create awareness of this structural problem but not solve it. Or, conversely, socio-technical integration in research cannot solve the problem, but it can create awareness of it. The space for midstream modulation, in the cases we studied, was shaped by gateways that were opened further upstream, and the anticipation of market and industry reactions to be encountered further downstream. In accordance with the STIR literature, this article shows that greater efforts are needed beyond midstream constellations in order to bring about a departure from techno-economic imperatives in technoscientific research. Moreover, however, by pointing out the "lack-of-agency" and the "reconciliation-after-all" patterns of argumentation, the article could shed some light on *how* the techno-economic innovation paradigm is able to become resilient towards critical questioning, thus stabilizing upstream and downstream imperatives within midstream research practices.

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