How do we arrive at constraints?

Articulating limits for computing

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ABSTRACT

Computing within Limits invites considerations of limits and constraints in design practice. We compare two projects which integrate constraints, the reduction of academic air travel and a solar powered internet, to show a distinction between two approaches to arriving at constraints. In the case of reducing academic air travel, the problem which greenhouse gas emissions pose for business-as-usual academic travel is addressed by proposing constraints on future flying. Constraints in the Flight project can be understood as a process of commensuration, of comparing that which is to be constrained according to a common metric. This gives rise to a future of academic travel understood in relation to CO2 emissions and reduction targets. In the second case, we have explored the solar internet as a specific way to introduce constraints in the context of the rising electricity use associated with internet infrastructure. In the Solar Internet project, constraints have been approached relationally and iteratively, in reconfigurations of internet use practices and design practices, including the solar internet imaginary and the scale of battery and power supply.

We compare these two approaches, drawing on vocabulary from Sociology of Quantification and Science and Technology Studies, to help articulate their respective implications, while also acknowledging what they have in common, e.g. the ability to expand the frame of what is made relevant for design practice. The case of the Flight project suggests that constraints as a process of commensuration can be fruitful when pursuing a unified future, intervening over time with a trajectory towards a quantifiable target. On the other hand, when trying to account for indirect effects and the future as multiple, the introduction of constraints can better be understood as con-figurations, with a future negotiated iteratively in design practice. Rather than thinking about constraints as essentially requiring one or the other approach, we suggest that problems and the introduction of constraints may be more or less amenable to either approach at a specific time.

KEYWORDS

Constraints, configuration, commensuration, solar internet, academic travel

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1 INTRODUCTION

The finitude of planetary resources, global heating caused by the burning of fossil fuels, and damage to the Earth's ecosystems are increasingly pressing concerns that need to be addressed. Economies and societies have developed under the assumption that resources and especially energy are plentiful, inexpensive and abundant [3], and the wider consequences (e.g. carbon externality causing global heating) have been mostly ignored.

The dominant way of developing services has been characterised in terms of a cornucopian paradigm where a human-centred design process foregrounds certain aspects, while bracketing sustainability concerns [13,18]. Computing resources are seen as infinite and always available, both from the developer's and the consumer's perspectives. To enable this "cornucopia" and always-on availability creates an increased electricity consumption for data servers, infrastructure and redundancy systems. While partially offset by efficiency gains [8], data servers' electricity consumption is prognosed to increase, especially with current increased use of AI and machine learning applications. Contemporary computing is also reliant on mining for minerals with a considerable impact on landscapes and those who inhabit them [2,11].

Academic air travel is another representative example. Within academia there has been an institutionalisation of mobility, with international academic travel to conferences, symposiums and other international activities [23], which have been criticized for their high carbon emissions [1]. While the effect of international travel in career building is unclear [7,25], these activities have increased as the need for publishing, presenting and networking for researchers is speeded up in the current academic environments [15,24] and the current economics of traveling allow relatively easy access, at least for academics in the global north. Increased academic air travel can also be argued to partly be an effect of computing technologies, as the internet makes it easier to organize international events and networks, but does not eliminate the need for occasional face-to-face interactions [26,27].

Academic air travel and the cornucopian paradigm are not unconstrained and do not exist in isolation. This was brought into sharp relief with travel restrictions during COVID-19 pandemic, the steep rise in natural gas and electricity prices in Europe in 2022, and supply chain problems. Constraints can thus be experienced by way of reacting to rising costs, such as those caused by systemic or external events affecting global markets, and to regulatory changes, in this case related to national and international health regulations. Additionally, Sustainable Interaction Design [13], collapse informatics [28] and computing within limits [29], suggest a path where information technology and air travel could also be restricted already in design practice, e.g. incorporating considerations for finite planetary resources and global heating. Hence, constraints can also be intentional, either for preparing for future availability problems or to mitigate current negative impacts.

The future proposed within the cornucopian paradigm is quite different from one grounded in a critique of business-as-usual where constraints are deliberately created. This discrepancy raises the question of how constraints are made and with what consequence, and suggests that what is constrained or not could have been otherwise. While there might be a tacit consensus in the LIMITS community that business-as-usual is a future we do not want, there is certainly debate on what our desired futures should be. With the constructed nature of constraints in mind, we are interested in the process of how we arrive at constraints and unpacking how we collectively negotiate and envision futures.

In this paper we draw on two cases of projects working with constraints: a) CO2 emissions limits in academic travel, and b) solar powered internet infrastructure. Based on the experiences in these projects the paper proposes two concepts which help articulate the differences in the two approaches to arriving at constraints. These concepts, Commensuration [4] and Configuration [16], also help us in pointing out some tentative conclusions about the different effects of the two approaches.

2 RESEARCH APPROACH AND CASES

Our paper is based on two narratives describing the process of arriving at constraints in two projects, which in this paper we call the "Flight" project and the "Solar Internet" project. All authors are part of the Solar Internet project at the time of writing, with the second author also having been part of the Flight project. While there is a shared notion of constraints in the projects in so far as something is to be restricted in their respective domains of air travel and internet infrastructure, our focus is on the process of arriving at constraints. In order to describe the process of arriving at constraints in the Solar Internet project, all authors prepared two paragraphs responding to the question "Based on your experiences of collaborating in the Solar Internet project, how should we define or frame constraints for the Solar Internet?" in written form, which was then used as the starting point in a discussion with all authors. During a subsequent video meeting, we recorded our discussion, and the partial transcription of the discussion became the basis for the analysis of the Solar Internet project. In discussing the Solar Internet project in section 3.2 of this paper, quoted passages are from those written paragraphs of the transcribed conversation.

2.1 Flight Project

A 2020-2022 research project at KTH Royal Institute of Technology, "Decreased CO2-emissions in flight-intensive organisations: from data to practice" aimed to support the university's goal of reducing carbon emissions from business flights. These goals were stated in clearly expressed numbers, e.g. decrease CO2 emissions from flying by 50% between 2015 and 2030. Lack of high-quality baseline data from 2015 and complications such as the Covid-19 pandemic introduced uncertainty, but the goal can for all practical purposes here be assumed to be to reduce CO2 emissions from flying by 50% between 2019 (the last year before flying patterns were altered due to the Covid-19 pandemic) and 2030.

With good baseline data coming directly from the university's travel agency, which is mandatory to use for staff, it is possible to calculate a CO2 budget. Furthermore, it is possible to design tools (carrots and sticks) that any organization could use to make sure it does not overdraft the CO2 budget, in much the same way organizations habitually work in relation to "ordinary" monetary budgets.

Many universities are to be considered flight-intensive organizations since academics travel both frequently and far. There can exist an awareness and a willingness to change travel patterns at a managerial level, as expressed for example through institutions' stated climate goals. However, in the parts of the organization where actual travel decisions are made, there is a lack of awareness and tools to manage these challenges. Furthermore, while overarching goals might be clearly formulated, there are few instruments to control and follow-up actual travel data and emissions and to use suitable means of control to ensure that stated goals are in fact reached.

The Flight project has been action-oriented, where the aim has been to develop and evaluate tools to reduce travel-related CO2 emissions. By using a formalized method combined with analog and digital tools, the project has tried to take stock, visualize, design, plan and mediate negotiations about individual and departmental CO2 emissions. In doing so, the goal has been to give flight-intensive organizations greater opportunities to reach or exceed climate targets, thereby contributing to an energy-efficient and sustainable future. In section 3.1 below, we recount the chain of reasoning in the Flight project in translating the KTH goals into something more actionable at the organizational level where decisions are made.

2.2 Solar Internet

The Interaction Design for the Solar Internet project is another project at KTH Royal Institute of Technology, running from 2021-2024 and funded by the Swedish Energy Agency. The project proposes the constraints of powering the internet through solar power as an arena within which to understand and design for a constraints-based interaction design. In this sense the project begins from questioning the role of constraints in design processes, using the physical constraint of the relative absence of sunshine in Swedish winters to provide a real and metaphorical driver for rethinking how we approach designing interactions on the internet. The project is less driven by an explicit metric for a reduction; even the specific constraint of sunshine (and the energy it can generate) varies from day to day.

Starting from the existing experiences of running solar powered servers in *Low Tech Magazine* and related initiatives [21, 22], the project has explored, developed and tested several technological options. The first explorations focused on using readily available, off-the-shelf equipment. For the first prototypes we acquired our hardware at a big-box store, with an approximate cost of €200 at the time of writing:

- a low-cost polycrystalline 100 W solar panel,
- a simple MPPT regulator for 12 V with a USB output option,
- a set of cables with MC4 connectors for connecting the solar panel to the regulator, and
- a reused 20 Ah lead-acid battery and cables.

The server stack for the Raspberry Pi versions is a standard Linux setup, in this case using Raspbian as operating system and Nginx as web server. To reduce data and energy the websites are served as static files. The websites are created using Jekyll in a development environment, and the generated static files pushed to the server. This means that the server does not use a database, nor needs to generate content on request.

The preliminary technical test, during a whole season in Sweden, shows that running a simple web server with low-energy devices on a cheap solar system is possible. From spring to early fall the version with a full-size Raspberry Pi 4 8gb (average current of 265 mA) worked perfectly and it could handle a heavier web setup than the one we used. During late-fall and winter the Raspberry Pi 4 drained the battery too fast and a version using a Raspberry Pi Zero 2W (average current of 100/124 mA (idle/request)) was a better option. Temporary downtimes were still experienced during the darkest period of December to January, with the system going down during the night on several occasions and starting again during the day. After a sunny day in January that re-charged the battery, the system did not have further downtime based on energy availability.

A barebones version using Arduino was also tested, using an Arduino Nano 33 serving HTTP from a text file in a hard-coded Arduino sketch, could bring down the energy use down to 55/80 mA (idle/request), which could be an option with very low energy availability, but was not needed with the current setup.

3 Arriving at constraints

3.1 Flight: Constraints in processes of commensuration

As mentioned in 2.1 above, the Flight project aimed to support KTH in reaching set targets for reducing CO2 emissions from flying by 50% in a decade. The chain of reasoning behind the constraints as understood in the Flight Project stretches backwards in time to events on the world stage (The 2015 Paris Agreement, #1 below) and established voluntary climate goals for Swedish Higher Education Institutions (#4 below), and forwards in time to encompass implications of the university's stated carbon emission reduction goals (#6 and #7 below):

1. While the Planetary boundaries [14] enumerate 9 limits that should not be overstepped, much of the sustainability discourse focuses on one particular limit, namely CO2 emissions (or more generally of greenhouse gas emissions as measured in CO2 equivalents) into the atmosphere. The 2015 Paris Agreement [17] stipulates that global warming should be limited to a maximum of 2 degrees (but preferably closer to 1.5 degrees) compared to pre-industrial temperatures.
2. Taking into account that most CO2 emissions from human activities remains in the atmosphere for centuries, other researchers [12] have calculated how much space remains in the atmosphere for additional CO2 emissions while not missing the targets of the Paris Agreements.
3. Yet other researchers have modelled at what pace current global carbon emissions must be reduced so at to not overstep the "budget" for additional CO2 emissions in the atmosphere [19] and their answer is that global CO2 emissions need to be reduced by 50% every decade between 2020 and 2050 (e.g. three times in a row).
4. Almost all Swedish higher education institutions (HEIs) are signatories of the 2019 "Climate Framework for

higher education in Sweden"[1] [6] and have thereby committed to follow the Paris Agreement. The Climate Framework specifies that CO2 emissions from each university should be reduced by 50% between 2020 and 2030 and this includes CO2 emissions from business travel (which for all practical purposes are equivalent to flying).

5. Since KTH Royal Institute of Technology is one of the signatories, KTH is bound by the Climate Framework to reduce all its CO2 emissions from flying (as well as from all other activities at the university) between 2020 and 2030.
6. A 50% rate of reduction per decade is equivalent to a 20% reduction every third year (ten times in a row between 2020-2050) or an annual rate of reduction of 7% per year.
7. If we assume that CO2 emissions from flying are proportional to the distance flown [20], there is no way around the conclusion that flying itself needs to be reduced significantly, e.g that there are no easy answers or technical fixes such as electric airplanes or hyperloops). While increased efficiency (better jet engines, fewer half-full planes etc.) can make a difference, it is far from enough when the goal is to reduce CO2 emissions by 50% in a ten-year period.

Some of the goals in the list above have been set or calculated by the United Nations, by research papers and reports, by the Climate Framework and by KTH Royal Institute of Technology. Other goals have existed in an implicit and covert form, and have been teased out and expressed more clearly in the research project.

3.1.1 Commensuration. The exclusive focus on CO2 emissions in combination with the chain of reasoning (above) constitutes an example of arriving at quantitative constraints, which we have conceptualized by drawing on processes of *commensuration* [4]. Commensuration is a process whereby ephemeral and uncertain qualities are condensed into comparable units. These processes are productive of new social realities, enacting new relations between entities in terms of a standardized metric with particular temporal orders. It allows qualities to be aggregated and compared over time, and decisions to be mechanized [4].

In the case of the Flight project, academic travel came to be understood in terms of the metric of CO2 emissions. This metric was used in the goals set up by KTH and provided a particular way of introducing constraints, as well as a way for achievement to be evaluated. The way to intervene and constrain academic travel with commensuration is framed in terms of the CO2 emissions that result from it. As such, it provides a framework through which to understand how much academic travel is acceptable. Furthermore, the process also entails a specific way of thinking about constraints and the future. With constraints framed in terms of metrics, the Flight project, and the KTH goals it builds on, can produce a projection of future CO2 emissions. The differences between the first percentages of reduction and the last percentages required to achieve a goal become bracketed. Also, the timescale of constraint becomes subject to such equalization.

The Flight project illustrates how constraints through metrics create conditions of exercising authority at a distance [5]. The processes of commensuration in fact precede the efforts in the Flight project and goals instated by KTH. The Paris Agreements and the Climate Framework for higher education in Sweden already participated in defining metrics and were indeed preceded themselves by multiple other processes distributed over time and place which later paved the way for the formulation of concrete emission reduction goals at KTH.

As this case also shows, the introduction of constraints in terms of metrics can intervene in the context which the metric represents. Metrics can be said to be reactive [5] in that they can alter how we categorize and put things in relation to one another. In its aim to be action-oriented, it thus seeks to intervene in how academic travel is framed, now with a climate impact, with the metrics constraining people to do things differently, which in turn could re-distribute how resources are used.

3.2 Solar Internet: Constraints in processes of con-figuration

The understanding of constraints changed from the point of the early stages of the Solar Internet project, compared to the start of the project. At the proposal stage, the Solar Internet project was developed around the imaginary of a solar powered internet during the Swedish winter, and the sort of hard constraints that it would entail. According to the application, "[d]uring winter, for every square meter of solar cells, a Swedish home could consume 50MB of data per day, or 1 minute of video". However, as it turned out once the project got going, the 50MB of data per day dissolved as a hard constraint. The imaginary developed at the time of writing the application supported constraints-based interaction design and thinking, "but the reality of it is very different". On the one hand, the availability of solar energy makes for a variable hard constraint as it varies seasonally and day to day, although it does come in as an external factor to a development process in the sense that the availability of the sun cannot be negotiated. But more significantly, the hard limit is something which can be treated as always solvable by technology when resources can be expanded: "You could buy a bigger battery, buy everything, and so the constraint of solar power was not itself a constraint, right, it was a rubber band around a set of other things, which could be modified to exceed the hard constraint". This challenged the assumption that the initial imaginary of a solar internet that went hand in hand with hard constraints.

Although hard constraints could have been defined regardless, that would have rendered the solar internet imaginary superfluous in the making of constraints. If we specify that the solar internet must work with only the 100W solar panel, then it is the panel that

[1] The Swedish Climate Framework for Higher Education Institutions is available at: https://www.kth.se/en/om/miljo-hallbar-utveckling/klimatramverket-1.903489

is the limit that we push against and not the sun. No matter the number, once it is established, we start to design to be 'just under' that constraints. As such, the solar internet would have been transformed into a problem of optimization.

In our initial work of implementing a solar-powered server with battery (hosting webpages), when we ran into some constraints in December and January, we had to ask ourselves not about what limit we had hit, but what limits became more visible as we exceeded them. Having the server powered by an off-grid solar array had the effect of making resources visible where they are otherwise mostly abstracted for developers. In a solar powered system, adding more batteries or panels is an option, but then "you have to put the stuff in". Once the energy generation and storage infrastructure (panels and battery) is in place it creates constraints on the kind of hardware that can be run, which in turn creates limitations on memory and performance. As a consequence, the cost of bloated software becomes more consequential since it might imply that an extra solar panel might need to be installed. In the work of actually implementing the solar powered web server, it made constraints noticeable to the one doing the implementation. That is, rather than externalising the constraint – for instance, in the solar panel, working with constraints directly changes the developer's relationship to the resource use of the system.

Working with a constraints-based approach with the solar internet became a question of exercising restraint, rather than staying within the bounds of a limit. The need for energy resources becoming more visible does not in itself negate the option to put in another panel or battery. However, optimization of the energy resources towards consistent service and minimum blackouts also carries with it embodied carbon emissions as well as increased use of material resources (e.g. from production of solar cells or batteries). Although what constitutes a constraint can shift with the constellation of resources, their cost suggests a need to learn how to say 'that is enough', with constraints becoming "not a question of pure numbers" but one of judgement. As such, a constraints-based approach pushes back against a paradigm where problems await their solution, as more, whether that be solar panels, batteries or computing power, can be added.

In this act of 'holding back' and taking into consideration what is sufficient in the exercise of restraint, normative questions of what is enough and what is necessary also become part of the solar internet imaginary. With a constraints-based approach as an exercise in restraint, the solar internet imaginary shifts once more to also encompass questions of social justice. For example, we can choose to prioritise availability of public services, even if they are relatively resource-intensive (such as telemedicine which makes use of videoconferencing).

3.2.1 Con-figuration. In order to understand the process of arriving at constraints in the Solar Internet project, we can draw on the concept of configuration [16], which can aid us in thinking about how boundaries are created in the solar internet, in what is included and excluded in the imaginary and technologies which are produced together, which includes constraints. "To figure is to assign shape, designate what is to be made noticeable and consequential [16, p.49]". We have illustrated how constraints and the solar internet came to designate different things over time, most markedly when comparing the solar internet imaginary produced in the course of writing a funding application, and the constraints-based interaction that took shape in the work that followed. In other words, we have shown how the solar internet and constraints-based interaction are figured together, and in particular how what each designated can change.

As a conceptual frame for thinking about constraints, configuration can be a tool "for recovering the heterogeneous relations that technologies fold together [16, p. 48]." Furthermore, it has helped us in articulating that arriving at constraints is an action, and as our text above illustrates, a series of actions which involve imaginaries, humans, servers, solar panels which all change in relation to each other iteratively. We could regard the solar internet imaginary, and how it formed and transformed over the course of the project, in practices of application writing, server implementation, the mundane and every doing and talking about project management and planning.

Our description of arriving at constraints illustrates that constraints can be dynamic. The gradual changes of the solar internet show how the relationship between the imaginary, the constraints and the technical implementation and our research practices have the potential to transform. We have presented multiple figurations of the solar internet, trying to provide the different ways the imaginary of solar internet is figured, together with a particular research work practice (application writing, server implementation). Configuration can aid us in thinking about arriving at constraints as the (re-)drawing of boundaries, of what is included and excluded and thus noticeable and part of the problem definition (humans, batteries, servers, valuations of what is important or not etc). In the Solar Internet project, arriving at constraints was an iterative and relational process. Our description tried to show how the relationship of constraint-based interaction design to the solar imaginary shifted as it moved from application writing to working with server implementation. In the process, constraints shifted from hard constraints, to a dynamic and relationally produced notion of constraint where resources and constraints are produced together. Furthermore, in making this shift, the exercise of judgement, or the restraint, also became part of the process.

4 Comparative discussion

We have introduced the two concepts - configuration and commensuration - as abstractions that can be helpful for thinking about different ways of arriving at constraints. Our analysis of the process of arriving at constraints is grounded in two projects, introducing limits to CO2 emissions from air travel and the constraints of powering the internet through solar power. Hence, with our analysis, it has not been our aim to suggest that these concepts exhaustively capture what it means to arrive at constraints. Rather our purpose here is two-fold. Firstly, we want to show that there are different ways of arriving at constraints and with each approach that there are advantages and disadvantages. Secondly, with these differences in mind, we argue that it is important to recognize that different ways of arriving at constraints can be productive of complementary ways of understanding futures of computing within limits.

Constraints arrived through commensuration and configuration can both contribute to a frame expansion [9], such as in our cases, making the problem spaces of academic travel and internet infrastructure more complex than before the introduction of constraints. However, based on our two cases, frame expansion with commensuration and configuration can be said to differ in important ways. In the case of commensuration, the definition of the problem is defined in terms of a metric, which sets a boundary around how the solution can be developed, which will also be understood in terms of this metric. By contrast, constraints in configuration will treat the relationship between the problem and the solutions as more open-ended and able to integrate more aspects as they emerge.

A further difference between constraints in configuration compared to commensuration has to do with how we populate the problem space with whos and whats. With commensuration, the boundaries around the phenomenon are more fixed compared to configuration. Hence, differences, those that cannot be measured according to the metric, become occluded and a set of homogenous objects are produced. Information is discarded and reduced but is also organized into new forms [4]. What is valued and brought to attention is deeply entwined with these processes of commensuration, thus warranting close attention. The metric presupposes certain continuity in what constitutes an entity over time and fixes their relationships in certain ways. Thinking about the problem of academic travel in terms of a CO2 metric forecloses future changes, which at least potentially could involve even more pressing problems emerging subsequently, or changes in the practices of academic exchange. Hence, it places limitations to the extent boundaries around people and technologies that populate the future and their relations can be changed. Here, constraints come to be understood in the same way over time and this is a time that can be uniformly divided, onto which milestones can be projected. Working with constraints in the Solar Internet project did not assume a particular temporality. Furthermore, the boundaries around who and what is subject to constraints, as well as what is to be constrained, can change iteratively. What is figured [16] could be reconfigured to a greater extent compared to the Flight project.

In making different entities comparable, the processes of commensuration arising with quantitative constraints also differ from configuration in the extent to which they are disciplining [5]. With commensuration, autonomy, the room for discretion and expert judgement in what should be constrained is limited, which could be valuable "when decision-making is dispersed, when it incorporates diverse groups, when powerful outsiders must be accounted to, when decisions are public and politicized, and when decision-makers are distrusted [4, p. 331]." Hence, there are situations when the ability to compare and enact accountability is advantageous.

However, performance indicators in higher education have previously served as illustrations of Goodhart's law, that 'when a measure becomes a target, it ceases to be a good measure' [30,31]. The accountability produced (in this case with a CO2 budget) at least runs the risk of "not measur[ing] performance itself, distort[ing] what is measured, influenc[ing] practice towards what is being measured and caus[ing] unmeasured parts to get neglected [30, p. 121]". Hoskin suggests that when measures become targets, they simultaneously become a description of what is, as well as what ought to be, creating calculable futures of paths to success and failure for self-examining subjects. In this conflation of *is* and *ought*, a contradiction can arise which may not be possible to resolve [31]. A CO2 budget for travel would currently be in tension with the institutionalized expectation of mobility. Should the expectations on the self-examining academic become to opt for a slower, less CO2 intensive, mode of travel to change travel practice towards what is being measured, this could exacerbate the challenges of making academia a career path also open to those with caring responsibilities [cf. 23].

What approach to arriving at constraints is appropriate depends on the context. In a certain situation metrics might be more easily adopted and there could be institutional support to make it more viable also over time. But neither the Flight project nor the Solar Internet are essentially well suited to either configuration or commensuration. Indeed, there are ways in which the problem of how to introduce constraints in academic travel could be reconfigured. Under such circumstances, constraints could be done differently by considering how CO2 emissions differ on long haul and short haul flights. Furthermore, it is wrong to assume that metrics are static, and depending on their entrenchment they could be revised and then the process could usefully be thought of in terms of reconfigurations. The differences between the processes suggest that there is value in being reflexive about how to arrive at constraints and that the limitations and advantages call for a plurality of approaches.

5 Conclusion

Within the current cornucopian paradigm, in activities such as academic air travel and internet use, resources are treated as if they were unlimited. However, the geophysical limits in resource availability, and the planetary boundaries on negative impacts such as global heating, challenge this paradigm, and provide an opening for alternatives, such as those that advocate implementing intentional constraints.

In this paper we have looked at two different projects that illustrate that there are different ways of arriving at constraints. We conceptualize two ways in terms of commensuration and configuration. Both of them produce an expanded frame with regard to their respective areas, academic travel and internet infrastructure, but differ in their respective advantages and limitations. We draw on our conceptualizations to contrast how boundaries and relationships are created, which affects the ability to adapt constraints, compare and make accountable.

By rendering these processes visible through these particular abstractions, we also propose that attention should be given to how constraints are made for computing within limits and that a particular approach does not fit all occasions. Different ways of arriving at constraints are productive of multiple futures which are complementary for thinking about computing within limits. It can be helpful to think in terms of Michael's [10] suggestion of an "ecology of futures" to highlight that these are futures made in particular contingent practices, that they can be realigned, subsume one another and that "perhaps there will emerge the possibility of a different way of enacting Futures in the future [10 p. 521]."

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