Infrastructure as Commons, Low-tech Principles and Territorial Distribution: a magical recipe for resilience ?

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Over the last few decades, we have seen catastrophic events emerging at an alarmingly increasing rate, such as climatic events, international conflicts, etc. Such events are due to ongoing and upcoming major crises, among them the climate crisis [23], the geopolitical instability and associated conflicts [1], the depletion of natural resources [9], etc. Such crises have and will have a huge impact on our societies. In particular, such crises induce impactful fluctuations on input resources (i.e., dependencies) and operational conditions of ICTs (Information and Communication Technologies), such as: energy [25, 29] and water availability [28]; climatic and atmospheric conditions; network-specific resources, such as connectivity or frequencies [5]; hardware availability [26] and software and services availability [7, 8]. The above fluctuations also highlight the *digital fragility*, which could cause major, repeated, and potentially long-lasting failures. Indeed, most digital infrastructures are not able to handle such fluctuations because of their performance-oriented design and management. For example, the paradigms of infinite resources, hardware homogeneity, and massive but relatively local replications are not robust.

Simultaneously, our societies decided to rely even more on said digital infrastructures, thus complexifying, multiplying, and pushing the use of information technology, resulting in a lot of interdependency loops in critical sectors. For example, power grid management systems are progressively relying on virtual services (e.g., virtual control command [27]) deployed in ICTs, and conversely, ICTs extensively rely on energy supply. In this context, one cannot ignore the looming disaster of cascading failures and collapse of vital services, which brings us to suggest in this paper rethinking digital infrastructure management and pushing in favor of *resilience rather than performance* to survive ICTs in a fluctuating world [16].

Our definition of *resilience* is broad and includes robustness, survivability, recovery (when possible), and adaptation [4]. If resilience in distributed systems has known many progresses over the years, it is still in its infancy regarding the above-considered crises.

As being researchers in software engineering and distributed systems, we give definitions of the above terms by referring to the IEEE standard glossary of software engineering terminology [17]. First, robustness is defined as: *the degree to which a system or component can function correctly in the presence of invalid inputs or stressful environmental conditions.* This definition is closely related to *fault tolerance*, often the preferred term in the field of distributed systems. Both terms focus on resisting or absorbing disturbances [13]. Second, survivability is close in practice to the *fail soft* concept (in contrast to *fail safe*) *pertaining to a system or component that continues to provide partial operational capability in the event of certain failures.* The survivability term was active in networks in the 90's (survivable network system - SNS) but almost completely disappeared with the introduction of resilience in the 2009 US NIPP (National Infrastructure Protection Plan) [15, 20]. When considering survivability, it is also important to consider the systems recovery, i.e., *the restoration of a system, program, database, or other system resource to a state in which it can perform required functions.* Finally, adaptability is closely related to the flexibility of a system, i.e., *the ease with which a system or component can be modified for use in applications or environments other than those for which it was specifically designed.* Adaptability is for us the last piece defining resilience, as in some cases, changes in the environment cannot be anticipated. In this case, being able to adapt, either to survive or mitigate the crisis, is the last resort.

In the following, we briefly suggest two paths to further study. Through them we suggest to think diffrently infrastructures design and management, to, we think, improve their resilience.

Infrastructure as commons and low-tech principles. While looking for resilient systems, we found one particular type of system that has a remarkable capacity to persist over time, sometimes spanning multiple centuries : resources managed as commons [24] (e.g. japanese irrigation systems, switzerland forest management). These commons are defined by three criteria: *a resource*, the hardware and the software on top of it in our context; *a community with boundaries*, the users, the operators, the developers (one can have multiple roles); *a set of rules* to avoid conflict and regulate resource usage. It is important to note that there is a difference with the digital commons [10], such as Wikipedia, because their resource to manage is knowledge, thus being infinitely expandable. Infrastructure as commons could be a key to resilience thanks to its adaptability. Indeed, as opposed to private companies or government entities, the commons offers collaborative decision mechanisms inside a community (rather small compared to industry standard), which enables knowledgeable people to directly take actions in the face of unexpected events. To take enlightened decisions, the full resource knowledge (machines and their software stack) inside the community is required. This is where low-tech principles [19, 2] are interesting to couple with commons, for instance, pursuing conviviality [18] and avoiding external dependencies. Not all principles of low-tech, e.g., usefulness, accessibility, sustainability, conviviality, etc., are directly applicable at all levels of digital infrastructures. For example, accessibility, as the ability "to make it and/or repair it locally", is difficult to consider at the hardware level. Indeed, even the lightest or simplest computer is already very complex and based on externalities [31]. However, not strictly thinking about computers as a whole, software stacks on top of hardware can follow the accessibility principle. Usefulness is also a sound low-tech principle for the resilience of a community, as it emphasizes the importance of reflecting on what is essential to the people maintaining the infrastructure. Finally, sustainability in low-tech means to optimize the environmental, social, or societal impacts of systems. This principle is, of course, adapted to build resilient digital infrastructures in the face of natural resources scarcity (e.g., metals, water, energy, etc.). To be applicable, both commons and low-tech principles limit the scale of the considered digital infrastructure, but they benefit flexibility and adaptability. As of today, combining low-tech principles on digital infrastructure and infrastructure managed as commons is new and needs further research. But, albeit non-academic and still in their infancy, some collectives such as CHATONS [6] are headed toward this direction. Also, while not exactly similar, community networks managed as commons have been developed in the last two decades, most notably guifi.net and Freifunk, studied by NetCommons [22].

Territorial distribution. The three types of crises cited as examples at the start of the paper occur at different scales within our territories. For example, depletion of metal resources is worldwide, while water scarcity is local; heat waves can affect all of Europe, and cyclones are local. Similarly, geopolitical conflicts and threats can be localized or worldwide. Geographically distributing digital infrastructures (e.g., data, services, machines) in territories is a well-known concept at the root of fault tolerance [14]. This field has been studied for a long time, but has been difficult to apply in practice. For example, operating a massively distributed infrastructure (e.g., Edge computing) is difficult in practice because it is often cost-sub-optimal for providers. Furthermore, today's infrastructure often needs particular properties, such as high network connectivity and high energy delivery for consumption, resulting in a concentration of datacenters around certain areas [12]. First, from a service-oriented viewpoint, achieving geographical distribution is not sufficient to be resilient to the considered crises: distribution has to be combined with dynamic territorial aspects. Indeed, heavily and constantly covering the territory of all possible data, or services, etc., is not necessarily the most resilient approach, as some areas are dynamically more prone to crises than others over time. The nature of the crisis may also imply different strategies, from massively local distribution of services to much more centralized services. Furthermore, taking geopolitical, hydrological, and climatic models into account in distribution, replication, and redundancy decisions, and being able to change them quickly, is important. Second, from a hardware viewpoint (while being much less prone to dynamism), making local/regional/national flexible implementation of small infrastructures (access to energy, connectivity, hardware material) could broaden the range of potential locations and favor territorial distribution of services.

As far as we know, research on these subjects is quite new. However, there are some similar fields in the literature. *Collapse informatics* [30] (introduced more than 10 years ago) suggests taking as a hypothesis that a collapse of our societies is plausible, that it will not occur violently but progressively, and that we need to think about how computer science could help in such a world. *Computing within limits* [21], published in 2018, focuses on three aspects: current and near-future resource limits (e.g., materials, energy); how new forms of computing may help support these limits; and the impact of these limits on computing. While not completely academic, we have noted some interesting civil initiatives to look at. For example, Deuxfleurs [11], a member of CHATONS mentioned above, is an association providing digital services, with a strong emphasis on digital materiality, digital limits, and inclusive governance [3], which joins our research direction on commons and low-tech. Furthermore, Deuxfleurs adopts a geographical distribution of its machines and services, which could favor territoriality.

The above-suggested pathways to resilience could also lead to acceptability issues. First, the proposed shifts could not be welcomed by infrastructure providers and users, and could even be radically rejected (e.g., essentials, degraded performance). Second, associated resilience levers could require political or societal radical decisions to be applicable (e.g., limits, quotas, priorities). We think interdisciplinary research between computer scientists and social and technical sciences is necessary.

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