

Permacomputing Aesthetics: Potential and Limits of Constraints in Computational Art, Design and Culture

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ABSTRACT

Permacomputing is a nascent concept and a community of practice centred around design principles that embrace limits and constraints as a positive thing in computational culture, and on creativity with scarce computational resources. As a result, permacomputing aims to provide a countervoice to digital practices that promote maximisation, hyper-consumption and waste. It seeks to encourage practices as an applied critique of contemporary computer technology that privileges maximalist aesthetics where more pixels, more frame rate, more computation and more power equals more potential at any cost and without any consequences. We believe that such a critical practice can be relevant to artists, designers and cultural practitioners working with computer and network technology who are interested in engaging with environmental issues. This is particularly relevant given the tendency in art, design and cultural production to rely on tools and techniques designed to maximise productivity and mass consumption.

In this paper, we argue for the potential of permacomputing as a rich framework for exploring creative design constraints building on a long history of applying constraints in art, design and cultural practices. Because of the need to reconfigure the modes of production and organisation within computational practices, this calls for a different understanding of aesthetics, one that goes beyond the formal evaluation of how things look, but addresses how aesthetics can also be systems of relations, sensing and making sense that are already present in the process of making. We will also discuss the challenges faced by permacomputing practitioners, such as the complicated link with retro-computing, post-digital culture and nostalgia, as well as the problem of constraints in relation to the aestheticisation of poverty, and more generally what it means to work with self-imposed limits in a more privileged socioeconomic context.

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CCS CONCEPTS

• **Applied computing** → **Media arts**; *Personal computers and PC applications*; • **General and reference** → *Computing standards, RFCs and guidelines*; • **Hardware** → **Impact on the environment**; • **Software and its engineering** → *Software design engineering*.

KEYWORDS

permacomputing, aesthetics, computational culture, art, design, cultural production, constraints, environmentalism, electronic waste, re-use

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1 INTRODUCTION

Permacomputing, a blend of the words permaculture and computing, is a potential field of convergence between technology, cultural work, environmental research, and activism. In essence permacomputing aims to promote and experiment with a more sustainable relationship with computer and network technology. At a time when computational culture seems to be increasingly characterised by electronic and energy waste, permacomputing instead encourages a more sustainable approach by maximising the life of hardware, minimising energy consumption and focusing on the use of already available computing devices and components. As a long-term utopian project, permacomputing aims to “give computers a meaningful and sustainable place in a human civilisation that has a meaningful and sustainable place in the planetary biosphere”.^[40] The term and this vision of computation was introduced in 2020 by Ville-Matias Heikkilä,^[40] an active participant in the *demoscene*, a subculture of practitioners working creatively with computer technology to produce technically challenging audiovisual works, sometimes under technological constraints, such as extreme file size limits or a choice of hardware with very little computational power. Artists and designers generally make extensive use of ICT and may be software and hardware developers themselves. Therefore, this techno-aesthetic context of sustainability has drawn media artists, designers, creative programmers and cultural workers to the term against the backdrop of broader considerations about the role and

ecological impact of computer technology and infrastructure in the cultural sector.[76] In short, the creative aspect of permacomputing makes the term useful for addressing technology and environmental issues in the field of arts and cultural production, and this is the scope of this paper.

As a community of practice, permacomputing encompasses loose groups and individuals gathered around a wiki,[13] as well as a number of email discussion lists, XMPP and IRC chat rooms, various websites, and informal or more regular gatherings such as the permacomputing meetings at Iffy Books in Philadelphia.[11] Many began to use the term independently, unaware of each other. Likewise, the authors of this paper have contributed to the permacomputing discourse through a variety of activities: writing, lecturing, speaking at conferences, teaching or organising workshops, and making cultural works that explicitly relate to permacomputing. Because of the highly interpretive dimension of permacomputing and its rather distributed adoption, our analyses, hopes, and critiques of permacomputing must be understood as personal ones. In other words, in this paper we refers to the authors. Last but not least, our perspective is situated in the Global North, more precisely in Western, Northern and Central Europe. As a result, any generalisation will obviously come with some caveats and biases, but this is not as simple as it may seem, as we will discuss later.

In terms of digital aesthetics, Heikkilä has previously made a comparison between practices that assume infinite computational power and those that are informed by an understanding of the limits and constraints of their computational materiality.[41] In addition to technical and strictly ecological considerations, we believe that permacomputing also has the potential to challenge a certain vision of ICT offered by large technology companies that has a negative impact on society and, we will argue, offers a bleak and deceptive agenda. For this reason, the link with permaculture is important to emphasise the cultural, political and social potential of permacomputing and, more generally, climate justice. We believe that it is therefore necessary to approach the question of aesthetics beyond looking at the formal qualities of works, and to consider the aesthetics of permacomputing as systems of relations, sensing and making sense that take place in the process of making and working around and with computational constraints. For the field of art and cultural production, we argue that such permacomputing aesthetics could facilitate a transition from a system in which practitioners use the latest digital tools and media regardless of the environmental consequences, to a more strategic system in which digital tools and media of all generations, are carefully combined, crafted and used to form a less extractive practice.

To build our argument, we begin by discussing why we believe the digital aesthetics associated with practices that assume infinite computational power—what we will call maximalist techno-aesthetics—is deceptive. To offer an alternative, we propose to consider constraints as a form of partisan practice that would make the material and computational limits of digital works more tangible. We also argue that the introduction of constraints creates a conundrum that highlights the tension between these limits as freely chosen creative strategies and imposed external conditions, as a brief survey of constraints in art, design and cultural works will show. We present several permacomputing works that demonstrate this condition and discuss how they negotiate and contextualise

this engagement in their own ways. We also discuss the difficulty of situating this discourse in relation to post-digital aesthetics and nostalgia, as permacomputing practices seek to move across old and new media technology. We conclude with open questions about the limits of permacomputing practices, particularly in relation to issues of privilege, aestheticisation and cultural appropriation.

2 DECEPTIVE MAXIMALIST TECHNO-AESTHETICS

In an unfinished letter to Jacques Derrida, Gilbert Simondon describes a techno-aesthetic work as “perfectly functional, successful, and beautiful,”[77] where contemplation and joy arise from the fusion of aesthetics and technique. Simondon also points out that aesthetics cannot be reduced to the sensations felt by the consumer of a work. It also encompasses the sensations of the person who crafts, makes and creates the artifact, as well as the relationships with the instruments used in the process. We find that contemporary computer and network technology shows that this fusion can also be joyless and dysfunctional.

Always taking photos but never having time to look at them, files that can't be found or placed on devices or in cloud storage, losing the password to the password manager, stifling productivity apps, electronic document explosion while paper documents are still required, invalid usernames, everything becoming a website, baroque chains of dependencies, software updates required to keep using the same software, terms of service for pointlessly networked home appliances, customer support that can only be reached on social media, laptop leg burns, glued and soldered batteries, no service manuals or technical documentation to facilitate repair of trivial hardware failures, internet connectivity mandatory for offline use, AI generating non-sense with unscrupulous conviction, restaurant menus with QR codes, etc., the list goes on endlessly.[59] These observations need not be driven by nostalgic generational issues—a point that we will develop in a later section of this paper—nor by an anti-computer and network technology resentment, as in anarcho-primitivist critiques of industrialisation. They are banal reflections on the failed fusion of the technical and the aesthetic in most of the computational devices and tools that surround us today. A story of mundane, uninspiring and bleak anecdotal technological failures.

We call this maximalist techno-aesthetics, that is, aesthetics that are the manifestation of technologies driven by the myth of perpetual growth and infinite resources, aesthetics based on the ever-increasing complexity and resource consumption of digital devices that seek to justify growth through self-referential legitimisation, regardless of necessity or ability to even function properly. One of the most visible features of maximalist techno-aesthetics is the increasing density of information for its own sake: more pixels, more detail, more *fidelity* and more *connectivity* equals more *potential*, and yet this is very often broken and falls short of expectations. In the context of art, design and cultural production in general, this often translates into a constant rush and pressure to adopt new tools and techniques, while simultaneously accelerating the creation of new discourses around novel aesthetics that entirely avoid critique around these very new tools and techniques. This phenomenon is not limited to cultural production, but extends to all fields and sectors that have embraced, or have been embraced, by the digital

revolution with little questioning or choice. Welcome to *digitality*, a nineties idea [68] of an immaterial digital future that decades later is still an unfulfilled promise, a digital revolution whose online life is painted with a “massive palette of irrelevance and pointlessness to be explored,”[32] a *hyperaesthesia* of mediating sensors,[33] but is mostly full of crap. [16]

However, this issue is obfuscated by the dominant actors of the ICT industry in the form of an aspirational, accelerationist, techno-progressive discourse that essentially redirects consumers and manufacturers towards a growing space of possibility, towards unleashed potentials at our fingertips, towards a brighter future, or at least a future of science-fiction-like aesthetics. So-called seamless and transparent design, plastic virtual worlds, the Cloud, consciousness uploading, transhumanism, cryonics, democratising access to domestic workers via app-based anonymous delivery servants, Mars colonies, frictionless interfaces and digital workflows, virtual reality, lifecasting, hybrid and blended learning, avatars, omniscient AI, cashless societies, online shopping with near instant delivery by drones, and a lot of people staring at black mirrors in empty spaces with shiny floors while being surrounded by gorgeous wild nature behind glass. We are almost there, we can almost touch the future, whether it is utopia or dystopia, we will all live a technological dream of ultimate material mastery. We just have to push a little harder, wait a little longer, we are almost there, the Big Tech companies are taking care of constantly prototyping and refining this near future where everything is solved.

Bell and Dourish refer to this phenomenon where “motivations and frames are often written not merely in the future tense, describing events and settings to come, but portray a proximate future, one just around the corner.”[23] But while we are stuck in this modern adaptation of Zeno’s paradoxes, we continue to record, collect and archive a mesmerising amount of digital data in which we forget ourselves,[2] and why we are doing such things in the first place. In fact, this field of possibility acts as a hypnotic distraction that prevents one from engaging with what is essentially a worldview driven more by consumerism, data colonialism,[85] and an undemocratic niche of longtermist visions.[17] This is why we think that these maximalist techno-aesthetics are not only broken, but also deceptive. The more distraction there is, the more the ICT industry can offer dysfunctional but very attractive technical solutions to problems that are really political, social or economic in nature.[57] The negative social and environmental effects of this distraction can already be seen, for example, in bandwidth imperialism,[63] the high resource demands of AI art,[49] and more generally in *data saturation* as a tactic of Big Tech expansion and a means of creating dependency on their services and infrastructures.[46]

But it takes little effort though to peek behind the curtain and see what feeds the digital dream. Apple’s headquarters is a case in point. Its sleek, futuristic design is framed by an endless view of the bland, suburban, copy-and-paste, car-based, precarious, extractive worker-consumer culture that fuels a promise that is essentially based on white, upper-middle-class normativity and the privilege of a few in the Global North. The deception of maximalist techno-aesthetics is like Apple’s UFO building. It may appear to be a hermetically sealed object from outer space, but its origins are far more terrestrial and sordid. It is profoundly extractive and exploitative, and yet it precludes any response other than boarding the spaceship at the

end of a new product launch and diving further into the abyss of late capitalism. In other words, while ICT industry leaders often remind us that we live in the age of computational miracles,[19] these miracles are not more than a carrot to keep us running on an ever more demanding, polluting, divisive, draining and alienating treadmill, powered by the world’s scarce resources and for the benefit of a very few. Is this the best we can do with computer and network technology?

So when we talk about permacomputing aesthetics, it is not just about technical implementation, or about countering a broken maximalism with an exact opposite, such as an equally broken minimalism. It is about reimagining, dreaming, and experimenting with alternative ways of engaging with computer and network technology.[9] Artists, designers and cultural workers are often praised for their capacity to communicate, illustrate and raise awareness around social issues. It is up to us to begin to critically examine the ways we are dependent on the ICT industry, to rethink the ways in which they produce things, and to begin to address this on a practical and concrete level in our fields. Reflecting on the broken relationship between the technical and the aesthetic in the techno-aesthetics of maximalist computational works, and because we believe that the core of the problem lies in this deceptive promise of unlimited computational resources fueling all sorts of potential futures, we believe that a discussion of the grounding, and material limits and constraints of cultural production could be a promising site of activation. But how to introduce a notion of technological constraint when artists, designers and cultural workers are encouraged, pressured, and trained to constantly create with the latest and greatest mainstream hardware and software tools?

3 ART, DESIGN AND CULTURAL WORK UNDER CONSTRAINTS

Constraints are a fundamental concept in mathematics, biology, mechanics, design, economics, to name but a few. Art and design are no exception, and this is a topic that has been widely discussed, and it is beyond the scope of this paper to provide an exhaustive overview of the critiques, discourses, and reflections that have emerged from the relationship between cultural production and creative constraints. However, at the risk of making a hasty generalisation, what matters for the permacomputing discussion is that constraints in art, design and culture tend to fall into two categories: self-imposed and externally imposed.

Self-imposed constraints are perhaps the most widely known and cited when it comes to demonstrating, with more or less honesty, that *less is more*. They can be formal: the literary rules of the writers of the OuLiPo collective;[72] conceptual writing in general;[24] minimalism in music and visual art;[71] any notated work to be performed, executed, installed, manifested again, such as poetry, music, graphic scores, conceptual art, performance art, installation art, software and computational art.[14][79] They can also be self-imposed by the choice of technology used: early computer artists in the late 1960s and early 70s working out programs for plotters without screens;[87] the use of simple samplers, cassette tapes and basic turntables in alternative, underground and instrumental hip hop;[62] subsets of the demoscene subculture that focus on making extremely small audiovisual programs or deliberately use

old and limited hardware platforms.[34] Self-imposed constraints in art and design can also arise from the choice of ‘poor’ materials: *arte povera* in Italy in the 1960s, using materials such as wood, earth, scrap metal and industrial waste; making furniture from common sizes of construction wood[61] or from found industrial materials; making household objects from available small trees and branches in *Slöjd*. [83] More generally, self-imposed constraints in this context become facilitators and amplifiers of creativity, so it is also possible to refer to them as *fabric*, [39], or to redirect the discussion by emphasising the process. [58][26]

There are also constraints that, although they shape art, design and cultural works in fascinating ways, are not in fact the result of privileged cultural workers searching for novel creative processes. In certain circumstances, the constraints can be political: unofficial artists during ‘normalisation’ in Czechoslovakia (1970s-1980s) and elsewhere retreated from public space and galleries to nature and private homes, and to media such as concept, action, performance, land art and video, such as the dissident video magazine *Original Videojournal*, which was secretly edited and copied on school equipment. Limitations may also arise from working within restrictive copyright or uncertain legal status: 1970s ephemeral media circulation in Cuba; low-resolution bootleg videos on UbuWeb; shadow and bootleg libraries. Finally, constraints can be socio-economic: Soviet Constructivists using wood and scrap metal because other art supplies were scarce; 1970s artists using discarded materials to produce their work quickly and cheaply; [93] the ‘Free Furniture’ design ideas from the 1971 *Steal This Book* work by American political and social activist Abbie Hoffman; [45] the ‘street-level’ one-stop graphic design convenience stores in the Philippines. [3] More generally, while affecting creative processes and aesthetics, these constraints challenge privileged Western understandings of art, design and culture. These practices exist outside the cultural and creative industries because they are driven by working class struggles, the need to adapt and survive, and to make do with whatever means are available. Relevant elements of discussion can be found in the improvised creative solutions of *Gambiarra* in Brazil [31] or *Jugaaq*, applied to concrete problems by repurposing objects and with limited resources, including the unexpected reconfiguration of media saturation in South Asia. [75]

Having briefly established this rather simplistic distinction between self-imposed and external constraints, we reach the point where we must admit, not without some embarrassment, that if we are to use permacomputing as a means to address climate justice and the deceptive maximalist techno-aesthetics to transform art, design and cultural practice, our design constraints will exist in the grey area between these two categories, self-imposed and externally imposed. It would live in a sort of limbo, where an urgency is felt and translated into a practice, but the condition of that practice is not directly threatened or pressured to address that urgency, compared to situations where the urgency is much more tangible *immediately* or *directly* life threatening. This is not to say, of course, that cultural workers in the Global North, and more specifically North America and Europe, are automatically protected from environmental disasters. But they are generally in a more privileged position, both economically and geographically. In effect, this helps to maintain the apparatus behind the deceptive maximalist techno-aesthetics, and it delays action. So what would it mean to address

the urgency to the point of completely reconfiguring a practice? Is it dilettantism? Virtue signalling? Artivism? Or just a symbolic gesture? We will try to respond to this conundrum in the final section of the paper, but for now let’s discuss some examples of permacomputing design constraints.

4 PERMACOMPUTING AESTHETICS

In computing, constraints can be as relative as they are arbitrary; it does not take working with an 8-bit CPU to realise that the latest and greatest graphics card also imposes limits on any creative programmer. What distinguishes permacomputing from other approaches is the way in which it makes constraints visible and usable through its connection to material circumscription. The qualities of materials are also a driving force through which aesthetic choices are made, as much as how the aesthetics are produced through the selection of specific material maxima, so as to reflect environmental and cultural values. These choices might include: working with e-waste, [22] working with limited availability of hardware and energy, [74] using small files and low network bandwidths, [63] considering computing devices as heirlooms, using natural materials, repairability or designing with local, regional and subcultural aesthetics and materials in mind. Unlike Simondon’s techno-aesthetics, which may eventually iteratively find a pleasing equilibrium between functional technique and aesthetics, permacomputing’s techno-aesthetics are much more perilous because a third component is forced in: an informed and contextualised intention to address the social, cultural, environmental and economic externalities of maximalist computer and network technologies.

Returning to our sketch of constraints in art, design and cultural works, it may now be apparent that as much as permacomputing *truly* values the design constraints as playful and creative, [35] they also act as visible barricades, blockades, and pickets to express and make tangible the contemporary struggles that should not be ignored in the creation of these works. However, permacomputing aesthetics should not be misunderstood as belonging to an aesthetics of obstruction, for it is less concerned with the performative and symbolic dimension of its approach, [10] and is instead rooted in questioning the nature of its underlying process and the generative insecurity of its awkwardness. [78] For this reason, we believe that the aesthetics of permacomputing works always serve as an entry point to make visible and understand a situated intention in the creative process.

In practice, permacomputing exists as two intertwined strands: first, an incentive to reuse and repurpose existing computer technology and materials to create new works; and second, a list of continuously evolving design principles, to guide that very reuse and repurposing, but *also* to inform the development of new software and hardware when reuse and repurposing are not possible or relevant. At the time of writing, only a few works relevant to cultural practices have begun to use the term permacomputing to frame their practice. We will now briefly discuss some of these.

Computationally minimal art (CMA) can be described as an algorithmic art that idealizes low computational complexity as a source of beauty. [38] A prominent example of CMA, shown in figure 1, is Bytebeat, a type of computer music based on very short programs

that typically generate PCM sound as a function of time using basic integer and bitwise operations.[37] The visual equivalent of Bytebeat is sometimes called Bit art.[82] In the realm of very short programs, serendipitous discovery plays a much greater role than intentional design, and much of the aesthetic comes from the programming model and language. Since computationally minimal art can be created with any conceivable kind of computer, or even without a computer altogether, it represents the diagonal opposite of the high technological dependence of maximalist computer graphics and music as you may see in figure 2.

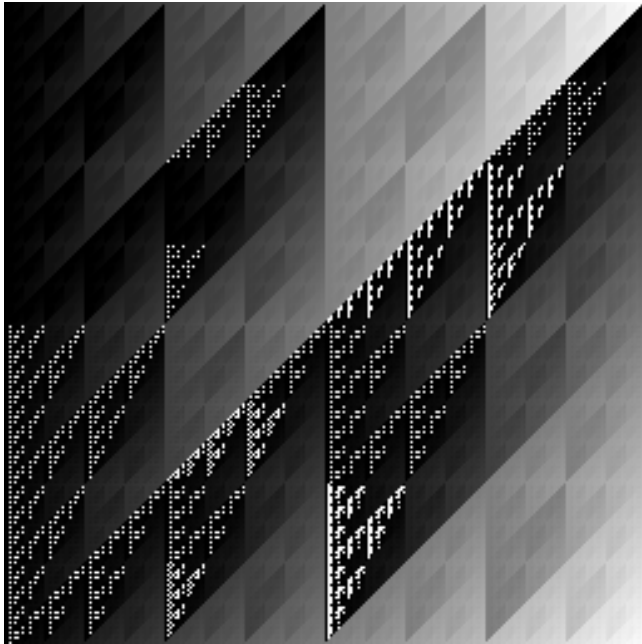


Figure 1: A bit art rendering of the bytebeat song formula $(t \& t \% 255) - (t * 3 \& t >> 13 \& t >> 6)$. Screenshot, Ville-Matias Heikkilä, 2023

Uxn is a small virtual machine geared towards small graphical applications, shown in figure 3, with features reminiscent of classic home computers.[48] It differs from most other *fantasy platforms* in its emphasis on low implementation complexity, and it has already been implemented on a variety of platforms including devices such as the Nintendo Gameboy Advance and the Raspberry Pi Pico. Uxn is being developed by Hundred Rabbits, a small artist collective living on a sailboat, as a platform for their own games and programs.

What Remains is a video game developed for the 1985 Nintendo Entertainment System (NES) console.[25] The game is the result of several years of research into the parallels between the manipulation of public opinion on environmental issues in the mid-1980s and today's climate crisis, and the role of whistleblowing in making damage visible.[18] The game subverts the nostalgic expectation of retro-gaming and is distributed by repurposing unwanted and overproduced game cartridges from the late 80s slightly modified to support the new game, shown in figure 4.

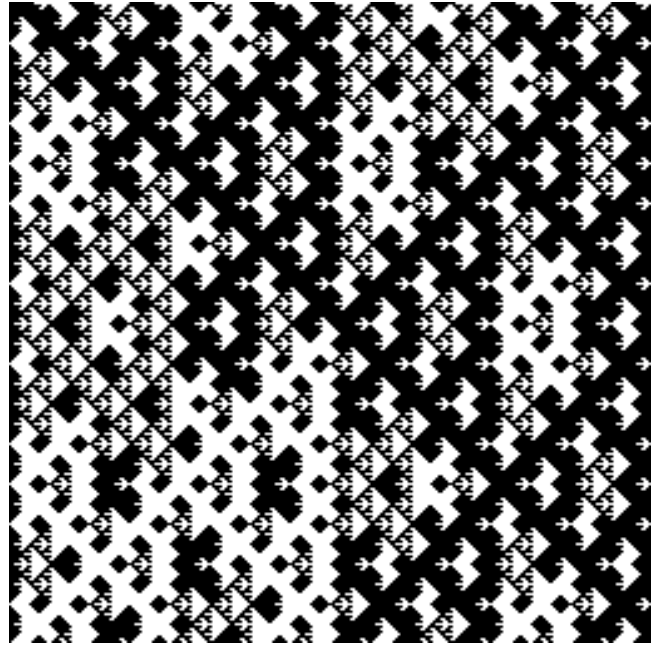


Figure 2: Bit art based on the formula $\text{abs}(((x + y) \& (x - y)) \% 24) > 9$. Screenshot, Ville-Matias Heikkilä, 2023

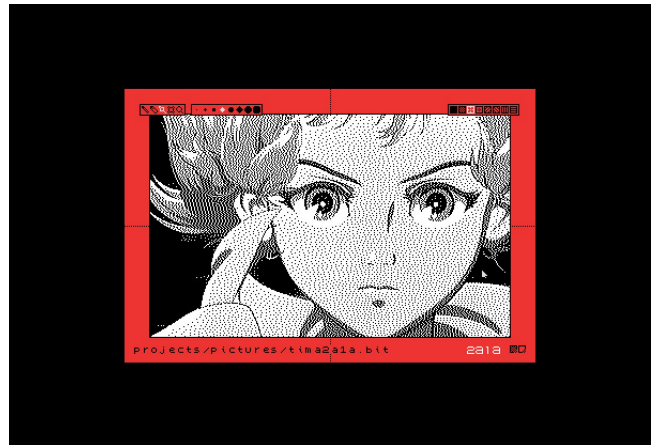


Figure 3: Noodle, a 1-bit illustration program for the Uxn virtual machine. Screenshot, Hundred Rabbits, 2021.

The Screenless Office is a system for working with media and networks using paper-based output from old laser and receipt printers.[47] A document camera, repurposed warehouse barcode scanners and simple buttons provide input. The system, shown in figure 5, allows reading news, browsing, reading and replying to emails, interacting with social media and playing local or streaming music. The creator frames it as an *artistic operating system*, not intended as a universal solution, but as an expression of the needs and desires of the author. The high latency of interaction and material



Figure 4: A cartridge of the game What Remains, made by player mi213 by repurposing an old game, and following the project DIY instructions. Photography, mi213, 2021.

awareness of environmental consequences work well with obsolete, low-power hardware and afford a calmer and more reflective pattern of use.



Figure 5: A test print on narrow receipt paper showing text and dithered images from social media. Photography, Brendan Howell, 2018.

The Livinglab, by Michal Klodner, is a concept for off-grid facilities for artistic and scientific research in nature.[51] The first such structure, seen in figure 6, was built in the forest of the Kras region of Czechia and has served, so far, as a site for ongoing experiments with solar power, silviculture and sound. The remoteness and low-power infrastructure necessitate and foreground permacomputing approaches for residents who wish to work with media or digital techniques.

Certainly there is no good or bad way to make a permacomputational work; it is highly experimental and interpretive. Some



Figure 6: Exterior view of the Livinglab in Czechia (Barrandien / Cesky kras region), Photography, Michal Klodner, 2022.

projects may be very strong in some aspects while neglecting others. The idea is that, by forming a community of practice around these two strands—first, an incentive to reuse and repurpose existing computer technology and materials to create new work; and second, a list of continuously evolving design principles, to guide that very reuse and repurposing—there will, we hope, be a process of both individuation and collective learning, mutual aid and inspiration.[86] For instance, in the current design principles for permacomputing,[13] the question of care therefore should extend the care of life in an ecological sense to include the importance of how we relate and talk to each other in a potential permacomputing community.[55] Accordingly, we, the authors, want to understand conflict and disagreement as generative contributions to the discourse and practice, trying to make sense of these things together, through making, publishing, self-hosted platforms and communication channels, online and offline events.[34] It is a highly agonistic process.[67]

This is why we think it is important to draw on a definition of aesthetics as the relational and distributed capacity to register, perceive and make sense of the world.[33] For us, this means that aesthetics also leads to questions of responsibility, particularly when working with materials, tools and techniques whose very nature actively leaves traces of extraction and exploitation in their making, use and disposal. Permacomputing could therefore be an effective cultural counter-voice to a digital aesthetic that encourages maximisation, e.g. high bandwidth, high resolution, more computing power at any cost, for anything, sensing and capturing more, while making less and less sense, ultimately rendering us insensitive to the harm and damage we legitimise. Above all, permacomputing should be understood as something symptomatic of the fundamental and enduring disconnect between the mythical, foundational, liberatory and emancipatory visions of computing and networking on the one hand,[8][69] and how contemporary computer and network technologies have failed to deliver this anticipated future. It is a response to the idealised fusion of the technical and the aesthetic in the maximalist techno-aesthetics discussed above, and its disfunction, which are subservient by-products of systems of extraction and exploitation.

5 PERMACOMPUTING AND NOSTALGIA

Following these examples and given the fact that permacomputing does not hesitate to promote the reuse and repurposing of old computing devices, or often eschews high-definition sound and visuals, it might seem obvious to associate permacomputing aesthetics with retro-computing. Is this a reasonable assumption? Simply put, no. However, we think it is important to nuance this response. Specifically, because retro-computing practices are so diverse and varied—from modders, hobbyists with disposable income, 8-bit computer collectors, to media archaeologists and hardware hackers—that it may not be the easiest way to begin to outline what is different with permacomputing. We think that a useful detour is to start by talking about nostalgia, time and consumerism.

In societies vastly dominated by technological novelty, economic growth, and technosolutionism, the relationship with time is difficult to dissociate from consumerism. This time, however, is of a peculiar nature. It is the time of quantified and monitored labour, the time of management, organisation and production coordination, and the time of economic cycles. Continuous updates of video games, TV/online series presented in seasons or launches of technological products—all coordinated in the context of strategic moments of increased consumption. Eras and generations are defined, analysed and symbolised by emblematic products of mass consumption. Our short lifespans, treadmill working conditions and short attention spans do not help us see these patterns, and instead support a productive apparatus that favours obsolescence, neophilia, amnesia, non-historicity, as a means to consume and produce more things. In this context, it has been normalised that any use of so-called *outdated* computing devices that have exhausted their economic value, can only be of a nostalgic nature, because such use makes no sense from the perspective of systems of constant production, consumption, creative destruction and reproduction. In a society where consumerism, modernity and identity are all linked,[64][73] out-of-date things can only refer to a past self, a past time.

For this reason, some activities around retro-computers and retro-aesthetics are in fact primarily forms of restorative nostalgia,[7] in the way they allow a connection to a past home, a past self, through objects of mass consumption. This nostalgia favours the cult of simpler times; the good old days when things were less complex and often associated with a privileged childhood. Retro-computing or retro-gaming events may include screenings of old series, films or anime that more or less correspond to the participants' childhood years. It is also common to find new faux memorabilia produced for playfully decorating adult rooms, and some console emulators go so far as to operate as VR simulations in which retro games can be played in a virtual teenage bedroom that has been carefully decorated to match the era of the device's production.[30] With the well-intentioned goal of creating a safe space for the literal emulation of a lost youth, such nostalgia runs the risk of fostering deeply conservative thinking and fetishising a past that never really existed. If anything, it prevents the problematisation[81] of an already flawed computer culture and opens the doors to imagined communities.[1] From a permacomputing perspective, it is impossible to long for a time when computer technology was better, because there never was such a day.

At the same time, there is an important aspect of retro-computing activities that can also challenge this argument: technical accessibility. It should not be underestimated that for many hackers, artists, designers and modders, the appeal of retro-computing lies in the relatively low-threshold capacity to augment, adapt or tinker with old equipment. From discrete components, socketed chips, annotated PCB layouts, and thick service manuals and schematics, retro-computing turns the maximalist notion of computational *potential* on its head. Even if everything is relative, and that black boxes of the past are just as closed as those of today, old machines are simply easier to take apart and understand. So if permacomputing could be aligned with retro-computing, it would be through some of the retro-computing subcultures that use so-called obsolete technology in radically different contexts because of its plasticity.[44] In addition to technical considerations, permacomputing also resonates with the creative and environmental considerations of zombie media[43]—a counterpoint to the notion of dead media—which acknowledges that “[m]edia kills nature as they remain as living deads”, and encourages the reappropriation of electronic waste, drawing an analogy with the processes of reuse found in remix culture. When Jamaican music studio engineers began experimenting with obsolete and abandoned US audio equipment such as spring reverbs in the 1970s, they were not nostalgic for 60s surf music. Instead, these machines became a core component of an entirely new musical genre: dub music.[89] In truth, permacomputing sees abandoned computing devices and e-waste as many different instruments waiting to be brought back to life, turned upside down and rediscovered to simply create new things. We believe that the end of a computer product's lifecycle should be seen as a moment of celebration, a moment when its socioeconomic context can finally be reclaimed, rather than put behind a glass and condemned to run the same old code forever as a consumerist trophy or fetish.

If permacomputing is nostalgic, it relates more to a reflective nostalgia that questions the truth of restorative nostalgia, by exploring different possibilities, and playfully combining together shattered fragments of memory, sentiments of longing, and critical thinking.[6] Ultimately, permacomputing aesthetics could be understood as a politically driven kind of post-digital aesthetics.[15] The latter are exemplary in bringing to light the end of the new media cult of digitality, while celebrating, or simply acknowledging the combinatorial and generative conflict potential of combining new and old media, ultimately to “look forward by looking back.”[28]

Of course, and to return to the question of time, we think it is essential for permacomputing to develop its critical practice by acknowledging both its relative and shifting position in an ever-changing landscape of new and old media. However, without falling into nostalgia and longing for a past that never was, and because of the way old computational devices take more time to do anything, permacomputing could easily be framed as a technological ally of the slow movement.[5] This connection would allow permacomputing to offer “alternative temporalities and experimenting with the affordances of slower tempos of computing and thus living”.[27] More generally, making the connection between a constraint—working with old computers—and a value—slowness—suggests that there may even be much more to learn from old media,[29] and this could further inform the permacomputing design principles and future

permacomputing projects, regardless of their association with so-called obsolete technology.

6 THE LIMITS OF CONSTRAINTS

As already mentioned, permacomputing is a nascent concept, and from our own practice, as well as looking at similar efforts, there are a number of issues that we think should be addressed if we are to rethink computational culture. In fact we think that the following points, while still approached through the lens of permacomputing and the field of art, design and cultural production, should also be relevant beyond this scope.

First of all, let's be honest, the more minimalist aspects of permacomputing suffer from the typical misunderstanding of simplicity in computation.[12] Opcodes are simple, but they're not accessible and easy to work with. On the other hand, machine learning image and text generation tools are not simple, but arguably more accessible and easier to use. This means that more than ever new approaches are needed to articulate the affordances of computer technologies in art and design academies, to justify the time needed for technical learning, especially in places that have first embraced code literacy in their curriculum and now face the dilemma of whether or not to teach prompt design. It should not be underestimated how difficult it is to raise this discussion in the context of art and design education, where the model for technological critique revolves principally around practical engagement with said problematic technology. The question of how to problematise computer technology and how to critique it while using it, without turning this use into a form of legitimisation, is unfortunately too often left in the background, as the tension between the use of computer technology as a creative instrument and the instrumentalisation of the cultural sector by the ICT industry, remains unresolved.[60] As early as the late 1990s, the question of low-tech versus high-tech art was articulated in the context of media art practices,[90] and little progress has been made since then, except to defuse the critique by commodifying it into yet another subgenre of media art and media design.

Worse still, the introduction of permacomputing into art and design education without proper contextualisation could lead to a form of romanticism close to the failure of the arts and crafts movement, which could end up reinforcing a bourgeois understanding of permacomputing craft as a luxurious and elitist product, thus preventing its radical potential as a popular cultural practice that could also exist outside of professional art and design circuits. This situation shows that there is a limit to tool criticism[88] when it moves from fundamental research to an applied practice. Similarly, the current fascination with the brokenness, repair and maintenance of things runs the risk of being misinterpreted. While it is undeniable that learning when things break[36] can be empowering, there is also a strange academic fascination with the innovative potential of things that break.[50] How do we move from an aesthetics of repair and reuse, which cannot be decoupled from questions of creative destruction and planned obsolescence, to an aesthetics of repair that can also admit that not everything should be repaired, and that perhaps sometimes things really do need to be left broken in order to escape the status quo of bargaining and negotiation that leads nowhere?

More broadly, while it is meaningful to frame permacomputing aesthetics positively as a kind of post-digital aesthetics, it is also a more problematic way to admit that permacomputing is entangled with the systems of production and consumption it seeks to critique, rather than being able to truly offer an alternative from the ground up. Put differently, the richness of combining old and new media, or the ways of working with more technological restraint with current computing devices, can also obfuscate the dependencies that such ways of working have, on the very neophilia that permacomputing seeks to address. Being entangled[4] can also lead to complete paralysis. This is not specific to permacomputing. It can be seen, for example, in software projects that are committed to minimalism or radically different ways of working and living with computer technology, but cannot escape the modern tools that can greatly facilitate this alternative. Worse, it is a real challenge to make such efforts visible and supported if their creators do not rely on social media and various cloud infrastructures, even if the latter are antithetical to their beliefs. Similarly, in the urge to develop more sustainable hardware projects, how do we deal with the fact that what appears—from a local perspective—to be alternative and fairer ways of producing still depend on a highly extractive and exploitative supply chain of globalised labour and manufacturing to which there is currently no alternative?

In high-income countries, the democratisation of the tools and infrastructure needed to engage in any kind of critical making in the realm of software and hardware often creates a dependency on the very systems it seeks to provide an alternative to, so much so that instead of providing an alternative, it helps to develop new symbiotic practices in which the answer to a problem can no longer exist without the problem itself. In particular, due to global efforts to create economic interdependence across the world, the scale of this dependency is currently so vast and so deep that it has led some to rethink entirely how to address such problems, for instance by shifting the reflection from the climate crisis and the means of production to directly addressing the means of climate production.[84] In more computational terms, it would be like trying to bootstrap a practice that is constantly debootstrapping itself. This raises the question of whether permacomputing can ever be transformative, more than performative and reflective, or whether it will remain doomed to be a kind of symbolic collective late capitalist gesture or swan song.

This brings up another limit for permacomputing. How to deal with the discrepancy between the discourse and its actual practice when it comes to issues of climate justice? How to align the ambition, the narrative and its situatedness so that it remains truly inclusive and more than just a few sound bites whose circulation will benefit only a few in a highly competitive race to the bottom, in a cultural sector that seems always keen to emphasize a short sighted and privileged articulation of care?[65] This problem of disconnection has been discussed extensively in related communities, for instance how the dominant narratives and ambitions of the maker movement have overshadowed other practices, as well as promoting individual heroic narratives while obscuring collective efforts, leading to a contradiction between the promises of empowerment and openness in maker culture and its other, very different realities.[53][42]

This contradiction brings us to another issue that needs to be addressed: the place of art, design and cultural works in relation to questions of class and privilege. While the permacomputing aesthetics and its appeal as an alternative computational practice may feel affiliated with grassroots DIY activism or practices from the Global South—for example, Brazilian cultural practices such as *gambiarra* and *mutirão*, briefly mentioned above—it is in fact unrelated. Alternative computational practices, such as permacomputing and other Western low-tech practices, cannot pretend to be distinct from the lineage of broad Western counter-hegemonic practices that operate according to an already legitimated logic of negation.[75] Moreover, the choice of alternative lifestyles and practices, not to mention the possibility of temporarily withdrawing from productivist, extractive and exploitative systems, is a sign of privilege and remains inaccessible to the vast majority of the population, even in high-income countries.

But it does mean that permacomputing is walking on thin ice and needs a lot of work to understand its own situatedness to avoid it ending up as a mere hobby for the most privileged, a romanticisation and aestheticisation of poverty, like many low-tech practices in high-income countries that end up as leisure activities. Understanding permacomputing's own situatedness is also necessary as groundwork for addressing harm directly where it is initiated and cultivated. In other words, how to create a space for critical practices that address urgencies such as scarcity and the limits of extraction, for example, in situations where no regulation yet exists to make these urgencies tangible. It is a fragile proposition, and, as discussed earlier, it still remains to be seen whether the use of artificial external constraints in the form of self-imposed creative restrictions, so as to address an urgency, raise awareness, and explore other ways of making cultural works can make sense in places that constantly give the illusion that we all possess a magical cornucopia.

There is a danger, therefore, that permacomputing aesthetics will remain just that: formal aesthetics that rely heavily on the cultural and stylistic appropriation of practices for which urgency and its constraints are necessities of life, not creative choices. This should in no way be taken as an excuse for giving up and embracing extractivism and wasteful practices, because sooner or later even the most protected regions will be profoundly affected with increasing material, social and economic consequences. For example, in parts of some high-income countries that are already severely affected by climate change, discussions have begun on the need to move from a static understanding of infrastructure to a more dynamic one that adapts to changes in the local environment.[56] In this case, there is a strong imperative and incentive to rethink the way we use and produce technology. This is an opportunity for permacomputing to be more than a symbolic gesture and sign of privileged activity, and instead to encourage cultural practitioners in the Global North to finally and actively reduce consumption and waste, while materialising a clear refusal to participate in the intensification of these problems.

7 CONCLUSION

In this paper, we have attempted to articulate how the field of art, design and cultural production could more meaningfully engage

with environmental issues by sketching an aesthetic understanding of permacomputing that goes beyond questions of form, beauty and, more generally, the artistic mastery of emotion through the skilful use of materials and techniques. Instead, we have drawn on a more relational and distributed understanding of aesthetics to propose an alternative to the maximalist techno-aesthetics promoted by dominant actors in the ICT industry.

Permacomputing's call to embrace constraints in this context recovers a sensitivity to and appreciation for limits in the creative process. We have argued that it is also a means of materialising an explicit resistance to computational practices that, while multiplying their capacity for sensing and opening up an ever-expanding field of possibility and granularity in the digital realm, are ultimately deceptive, exploitative, extractive and harmful. Permacomputing is a nascent concept and community of practice that is trying to figure out how best to develop meaningful approaches through common design principles. At the time of writing, it is still a work in progress. However, as active contributors to this emerging practice, we believe that there is now enough discussion, work and sharing to begin to consolidate some aspects. In particular, we discussed how permacomputing relates to post-digital aesthetics and nostalgia, in order to address misunderstandings, but also to highlight the potential shortcomings of permacomputing's paradoxical position as a practice that is interdependent with the systems it seeks to liberate itself from. This has also allowed us to further extend the boundaries of design constraints in the context of permacomputing, specifically addressing socio-economic reservations and the risks of cultural appropriation or aestheticisation of the struggles of groups and individuals who are far less privileged.

If the difficulty of naming things is a popular trope of computer science lore, the difficulty of not naming novel critiques of computer technology is even greater, especially when cultural workers are increasingly trying to articulate a new vocabulary to address contemporary technological issues and struggles.[21] At a time when it is increasingly difficult to articulate common causes[80], why do we need yet another term? From feminist hardware[91] to the issues of decolonising computing,[52] how do we put theory into practice in this increasingly complex semantic and discursive space? While there is enthusiasm for engaging with obsolete electronics, renewable energy and e-waste, what about our contribution to the waste of past and present ideas, concepts and initiatives?[20] How to forge alliances? How not to claim or define, and yet create a momentum at the cost of excluding and marginalising people while wasting existing work and ideas from other times or contexts?[66] How do we avoid the patterns of heroic narratives driven by novelty, competition, individualism, precarity, and a race to the bottom among increasingly precarious cultural workers whose survival depends largely on their ability to individually capitalise and brand specific discourses? How do we deal with superficial engagement and opportunistic virtue signalling? What is a *good enough*, ecologically meaningful computing practice for artists and designers? What is not good enough? Who decides? How do we negotiate and explain compromises while remaining gentle and careful with each other, rather than trying to judge the authenticity of one's actions based on petty, trivial technological nitpicking?

We cannot answer any of these questions definitively, but what is certain is that in the context of an abundance of critical theory,

permacomputing exists as a critical practice. It seeks to bring a hands-on approach to theoretical riddles[54] while resisting the artificiality of a lab experiment or an art installation. It tries to navigate this minefield through hacking, art making, design and cultural production. It makes mistakes, but at the same time tries to take a stand and defend a position. The use of the terms *barricade* and *picket* to qualify design constraints in permacomputing is not arbitrary. As we have recognised, it may be nothing more than another facet of trying to make sense of living under late capitalism.[70] Regardless, as practitioners of permacomputing, we want to invite our fellow cultural workers to challenge the paralysis of pharmakon critique. It is important for us to try to make choices. What kind of present and future are we constructing?[92] What kind of present and future are we promoting by relying on this or that computer technology or network infrastructure? Are we capable of leaving the hypnotic comfort of witnessing disaster in high definition? Are we capable of radical change? The choice is not easy, especially when we work in systems that dull our senses with mesmerising possibilities and promises, but we will try.

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