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doi: 10.1017/S1359135525100791



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1 **The 'POD' plays off the BOD (Building on Demand) and envisions a technical ensemble where the building is conceived of in parts, which are then printed 'on demand'.**

https://doi.org/10.1017/S1359135525100791 Published online by Cambridge University Press

Reflecting on challenges inherent to the development of a new building technology – 3D printing using wood waste – via French philosopher of technology, Gilbert Simondon.

PrinTimber: speculations on the technical evolution of housing

Randall Teal, Carolina Manrique, Dwaine Carver, Damon Woods

> *To find an adequate relation between man and the technical object, we would have to be able to discover a unity to the technical world, through a representation which simultaneously incorporates that of the artisan and that of the engineer.*[1]
>
> Gilbert Simondon

This article comes from a collaboration between the departments of Architecture, Mechanical Engineering, Civil Engineering, the College of Natural Resources, and a team from another University's School of Forestry and Wildlife Sciences (known collectively as the PrinTimber Group); the team was awarded a National Science Foundation Grant for 'Developing a Circular Bio-Based Framework for Architecture, Engineering and Construction Through Additive Manufacturing'. The focus of this work is to develop an additive manufacturing construction technique that repurposes the 20% of wood waste from wood-product manufacturing and wood construction waste that currently goes to landfills. The idea is to use this material in novel combinations with various additives to create a high-performance biobased construction material.[2]

At the inception of this project, we proceeded on a path of creating a SIP-like panelised system with the print team attempting to make a cross- weave version of a panel.[3] It quickly became apparent that not only the current state of our printing was a bit rudimentary for getting anywhere close to a SIP-like 3D construction (most of our early output looked like unappealing baked goods), but also the ultrafine composition of the '*wood flour*' (required for print flow) lacked the characteristic long fibres that make wood perform well in *both* compressive and tensile applications. In addition to these performance issues, there was the question how a 3D-printed panel was going to be a viable economic alternative to any factory mass-produced wood panel.[4] These factors opened discussions – looking to both workshop-centric and in-situ construction techniques – about how PrinTimber (P_T) could best leverage the material itself to meaningfully affect shortcomings of current practices of home building.

In what follows, we (the Design Team) use Gilbert Simondon to situate some of the challenges facing the evolution of P_T, believing that his thinking provides a useful intellectual framework for mapping technological development, evaluating project parameters, contextualising obstacles and challenges, and understanding the necessary transformations that must occur for P_T to have significant technological impacts.

Homebuilding evolution

> *Evolution is as much maladaptation as it is adaptation.*[5]
>
> Gilbert Simondon

In our region, stick-framing accounts for most residential construction. As such, we have endeavoured to consider P_T's potential impacts in comparison with this standard. That is to say, if we are to affect access to housing, particularly affordable housing, then we need to understand P_T's performance, desirability, and affordability in light of the performance, impacts, conveniences, and practices of stick-built housing. As such, we endeavour to consider the interplay between technical / individual / world (Simondon's 'individuation') by imagining the stick framed house as a Simondonian 'technical object'.[6] However, noting that ontological status of a dwelling place is ambiguous – is it a tool to aid human survival, a Corbusian 'machine for living', or mere milieu? – we proceed with heuristic intention.

Simondon's discussion of the technical object begins with a 1910 car engine, which he describes as a collection of autonomous elements made performative via their attachments to one another. Simondon calls this *analytic* state of the technical object an 'abstract technical object'. In this analytic state, one may discern a legible technical diagram in the specific collection of agglomerated parts; this diagram is the fundamental blueprint of the engine's technical essence.

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The abstract technical object may develop through successive iterations in a search for greater efficiency and better performance in a quasi-biological evolutionary process Simondon calls 'concretisation'; concretisation occurs as the collection of autonomous parts begin to fuse into specialised components and take on pluralities of function. Gradually this process yields a new *synthetic*, the 'concrete technical object', which is characterised by a decrease in the overall number of components, specific interdependencies amongst the remaining components, and a corresponding boost to the efficacy of the object. André Leroi-Gourhan's notion of a 'technical tendency', highlights the evolutionary aspect of concretisation. The technical tendency suggests that technical objects (like natural objects) possess a *telos,* and like biological entities, they tend towards certain ideal arrangements, for instance the technical stabilisation of form found in twelfth-century church bells.[7]

Regarding concretisation, one of the interesting aspects of a stick framed house is that it shows both the evolution and ideal arrangements one would expect, yet paradoxically its parts grow more numerous, and one might argue, less interdependent, over time. In terms of evolution, the platform-frame emerges out of refinements and transformations of log building, timber framing, and balloon framing. Stabilisation of this method grows with increased technical / logistical means of lumber extraction, the appearance of standardised dimensional lumber and the means to mass produce it – particularly the move from pit saws to circular saws, and the distribution and sales networks that bring the components (conveniently) to consumers.[8]

Interestingly, much of the normalisation of this system occurred prior to most modern building codes and standards such as electricity, plumbing, HVAC, and thermal insulation. Prior to the current era, home building would be what Simondon refers to as 'artisanal':

> *In artisanal processes, control by means of information gathering is frequent: man is simultaneously the driving force of the tool and the perceiving subject that regulates actions according to partial instantaneous results. The tool is simultaneously a tool and an instrument: it is a medium for action that extends the organs as well as a conduit for recursive information.*[9]

Here, a carpenter would simply be 'the builder', more or less constructing everything, and the 'design/build' nature of the artistic endeavour means that the carpenter understands that the design decisions and technical precision of earlier stages will either positively or negatively affect successive stages of construction. For example, if the structure is not plumb, the cladding will be more difficult to attach and potentially will be less effective – because of ensuing imperfections – at keeping air and moisture out of the wall cavities. As such, early in the development of wood construction we get a stage of concretisation where there are meaningful interdependencies such as diagonal 1x underlayment for cladding, which also serve as shear reinforcement for the stud wall.

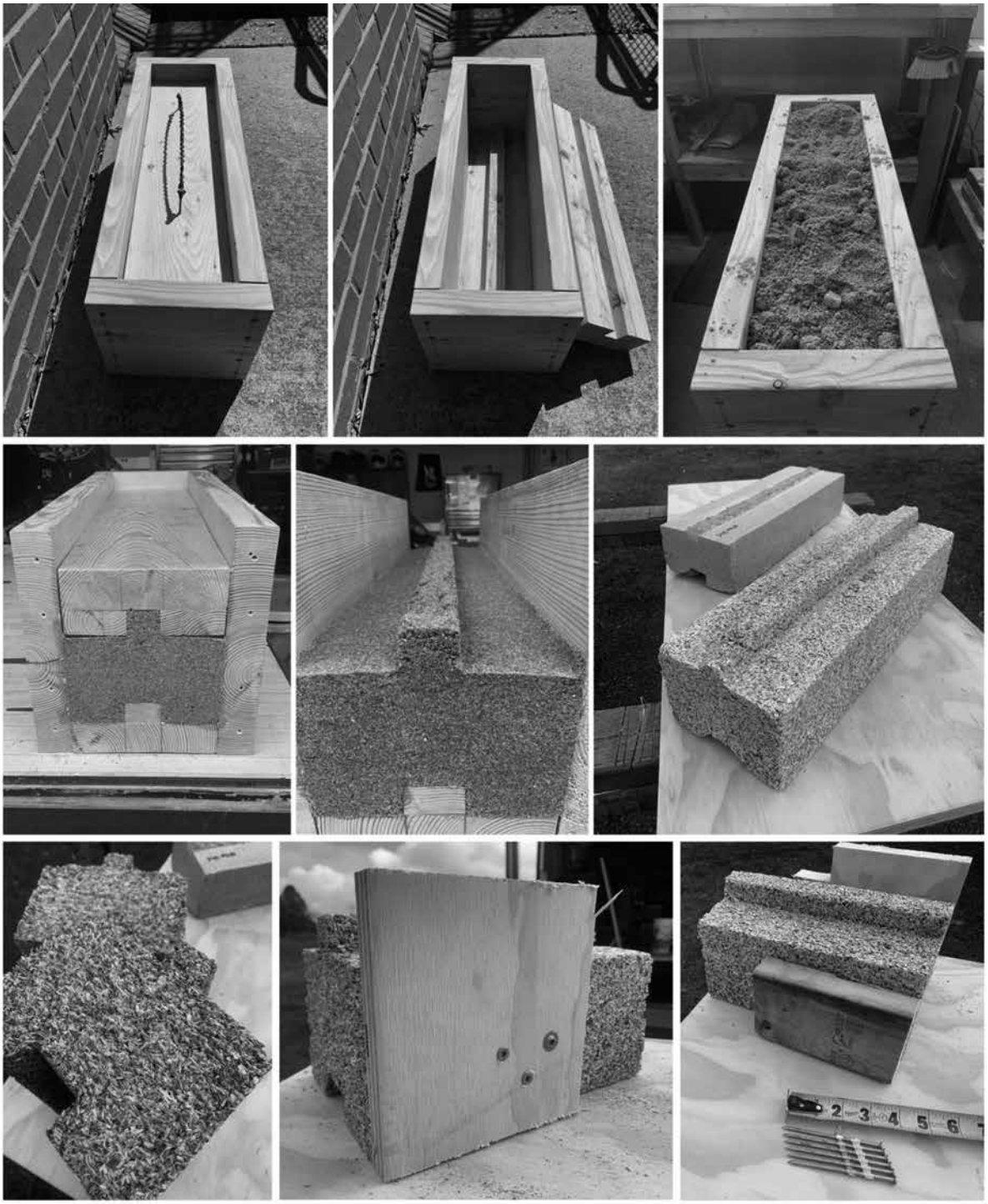
This artisanal system is later modified by new technical elements, and with the addition of electrical, plumbing, HVAC, and insulation the moderately concrete technical object 'house' regresses back into a more abstract form. The veritable autonomy of these new systems is like the elements of the abstract engine with each intervening, 'at a certain moment in the cycle, and then is expected no longer to act upon the other elements'.[10] These layered independencies of a modern building are summed up by the successive manner in which trades come in to build a house: first excavation and concrete, then framers, then roofers, then plumbers, then electricians, then HVAC, then drywall contractors, then flooring installers, then cabinet and counter installers, then bathroom tub and tile installers, and finally finish carpenters. Coincidentally, Simondon completes his thought on the abstract engine saying, 'the pieces of the engine are like people who work together, each in their own turn, but who do not know one another.'[11]

This comment, although unintended, sums up the independence of trades, their general lack of concern with the building beyond their 'job', and the autonomy of the building systems within the building proper. Here, it might be argued that the house has become *more* abstract over the past half century. The repercussions are that in regressing to abstraction, a construction 'uses more material and requires more construction work; it is logically simpler, yet technically more complicated, because it is made up of a convergence of several complete systems.'[12] In this process, and this is a key point as it pertains to P_T, the stick-framed house becomes caught between abstract and concrete, between the artisanal and the machinic. As such, it has become a monstrous hybrid that rarely benefits from the system *inter*dependence that artisanal processes create, nor does it benefit from the efficiencies of the machinic realm.

In our current era, it might be argued that the general contractor as the 'conductor' of the trades/systems, is the 'mutual interpreter of all of them in relation to one another'.[13] Although a reasonable visualisation, if true it leaves us with a super inefficient abstract machine that is sequence dependent, with explicit components that are not synthetic in any significant manner. And critically, there is very little that might be done to improve the efficiency or performance of the current system as it currently operates.

The above-described evolutionary picture of wooden home construction is illustrative of the unpredictability of the process of concretisation, as Simondon says:

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2 Various part of Techno-log manufacture. Top row (L–R): Mould with the top on, mould top off, mould filled with raw material. Mid row (L–R): compressed material in the mould, pulling the top off, taking the log out of the mould. Lower row (L–R): cutting a log with a chop saw, attaching plywood with various screws, attaching a 2x4 with a framing nail gun.

> *The actual evolution of technical objects does not happen in an absolutely continuous manner; it does not happen in an absolutely discontinuous manner either: it involves stages that are definable by the fact that they bring into being successive systems of coherence.*[14]

So, perhaps an apt description of the situation is as follows: prior to modern standards of construction the house was a relatively well-integrated and singular system of coherence regulated by artisanal processes that insured the interdependence of many components. However, with the addition of modern technical

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requirements there occurred a restabilisation with said technical requirements being assimilated *in terms of the prior model of coherence*.

This neo-abstract coherence provides an opportunity; creating a juncture for interpretation, which acknowledges the process of concretising as non-linear, or as Simondon says:

> *It is not enough, however, to claim that the evolution of the technical object occurs via a passage from an analytic order to a synthetic order, conditioning the passage from artisanal production to industrial production: even if this evolution is necessary, it is not automatic and one ought to seek the causes of this evolving movement. These causes essentially reside in the imperfection of the abstract technical object.*[15]

As such, this abstract juncture creates an opening to pose a new 'synthetic schematism […] *which precedes invention*'.[16] In other words, the house as shelter is a clear original schema laid out according to basic needs of shelter; the modern technological inventions have not been part of an original schematisation of home, thus currently exist in way that is incorporated, but not as part of a unique schema.

Printing concrete or concretisation via printing?

Printing a building sounds, at least superficially, like the opposite of what is described above. In fact, printing is a nice metaphor for both concretisation *and* sustainability: I create something on the computer, and I press print. Print is single-step execution, print is make only what you need, print is biodegradable, print is on call, print requires no staging, print needs no coordination of external constituents, print is free-complexity, print is access for all.

Perhaps, I go to Home Depot, and instead of picking up an assortment of building supplies and a bevy of tools at the rental centre, I buy some P_T *wood flour* and rent a printing robot.[17] I then give that robot a set of instructions straight out of the Home Depot design software; this software can be controlled by the proprietor, the professional, or the DIYer; it is a software where one not only plans the project but also specifies its performance (based on simulations programmed with local building codes and climate data). For example:

> *Make this wall 12 inches thick, it should be breathable with a perm rating of 25, it should have an R-value of 50, I need to horizontal chase at 14 inches for my wiring. The floor and the ceiling should be printed as integral with the wall; the floor will span 15 feet, have an R-value of 30 and have a surface with a Janka hardness rating of 1450, the roof will also span 15' it will be set on a 5:12 pitch, its perm rating is 0 and R-value 80. The ceiling surface will have the same flat "golf ball" color as the walls; the texture of both will be smooth and they should have an STC rating of 60 and NRC rating of .4* […] *PRINT*[18]

The Danish company COBOD started the process of 3D printing in the architecture, engineering, and construction industry (AEC) with its 2017 construction of Europe's first 3D-printed concrete building in Copenhagen. This first small-scale 'building-on demand' or BOD, was an office space of less than 50 square metres (538 sq ft), and was developed to demonstrate 'economic and architectural benefits of using 3D printing technology for construction'. This first BOD was constructed in two months using COBOD's first-generation 3D printer (BOD1); a second version reprinting the walls of an identical copy in 2019 using a second-generation printer (BOD2) took three days, demonstrating a steep improvement in the development of this technology.[19] COBOD and others such as ICON and Winsun have shown ways in which 3D printing technology might disrupt current conventional construction methods through enhanced productivity, reduced needs for skilled labour, and design freedom (e.g., complexity is free, as they say), and critically moving building towards a more, Simondonian, concrete end.

However, the misrepresentation of a '3D Printed House' has been a constant theme in the industry; most 3D printing technologies do not do foundations or roofs.[20] Although there are moves in AM to integrate reinforcement, electrical, plumbing, and insulation, thus far all of this is done through the addition of singular function components to the system;[21] windows, doors, fittings and finishes, insulation, mechanical, and renewable energy systems are all handled as add-ons external to the process of printing.[22] Additional concerns include durability (climate has a tremendous effect on performance and longevity); fireproofing; thermal performance; basic structural integrity (there have been concerns about a lack of stiffness in printed-concrete walls); there are neither codes or specifications for minimum standards, nor is there any track record for long term performance. At the most basic level, one might even ask – are these buildings safe?[23] Despite all of these areas of concern, one can reasonably assume baselines will be established in all areas of code regulated performance, which leaves the architectural / construction question of whether 3D-printed buildings are truly a revelatory proposition and if so how might it technologically evolve? Simondon sees two primary drivers of technical evolution:

> *It seems that of the two major causes of technical evolution, the first economic, the other purely technical, it is the second which is of greater importance* […] *areas of most active progress are those in which technical conditions outweigh economic conditions.*[24]

However, Simondon warned against economic motivators, because these are frequently the vehicle for incremental fixes, which pose as transformational agents, but actually impede technological advance, because they, 'blind us to the real imperfection of a technical object'.[25] He goes on to say:

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> *By dissimulating the true schematic essence of each technical object behind a pile of complex palliatives, minor improvements entertain a false consciousness of a continuous progress of technical objects, diminishing the value and feeling of urgency for essential transformations.*[26]

For example, as printing has moved forward the ease of constructing curvilinear walls has also been endorsed as an application of biophilic design principles. For example, ICON claims the soft corners of their 3D-printed support walls create 'naturalistic circulation routes throughout the home'.[27] This approach to biophilic design through soft forms claims to be aimed at 'the emotional aspect of humans' needs for interactions with the natural environment in the building environment'.[28] Unfortunately, such minor improvements are one of the primary strategies of creating demand, which adulterates technical progress with the 'false renovations' of capitalism. This adulteration applies to any number of products that brand, tag, or repackage some fundamental idea from flooring, to paint, to tools with new 'features' in order to create demand; minor improvements claim revolution, yet merely create cravings. Without such vigilance, realities such as the inconvenience of curved walls in housing projects that might require smaller spaces and difficulty with integrating furniture and appliances can inappropriately creep their way into the language of 3D printing; such 'minor improvements' will divert attention from real technical progress in AEC additive manufacture, elevating tool biases (i.e., the printer's preference for making striated walls with curved corners) and passing their effects off as 'advantages' when in reality these effects are superficial 'features' useful to marketing printed houses as consumer goods.

Further, Zhong and others have commented on the need to critically examine promises in 3D printing relating to the 'impacts and effects on sustainable architecture' with an eye towards 'green-washing or placebo strategies'.[29] And this need for watchfulness goes beyond 3D printing itself, regarding any number of products added to a building in the spirit of sustainability. Products such as: 'greener MDF',[30] a non-OSB/styrene SIP panel, or 'glass-based insulating gravel',[31] are not technological sea change; but rather, for better or worse, incremental improvements.

The awareness of what is 'fundamental' and what is 'extra' is critical in the context of neoliberal capitalism, where the demands of the market can work as both *incentive* to create consumer desire, as well as *disincentive* towards technical evolution. Industrial designer Raymond Loewey named the latter phenomenon 'MAYA' (most advanced yet acceptable). He explains:

> *Our desire is naturally to give the buying public the most advanced product that research can develop, and technology can produce. Unfortunately, it has been proved time and time again that such a product does not always sell well. There seems to be for each individual product (or service, or store, or package, etc.) a critical area at which the consumer's desire for novelty reaches what I might call the shock-zone.*[32]

For P__T, this comment points to both consumers as well as the AEC industry, which has similar thresholds of acceptability. 3D printing is already pushing up against some of these thresholds as Nathan Siems of ICON says, 'when you are disrupting an industry, which ICON is doing, there is a lot of change, and many people don't want to learn more about it.'[33]

New paradigms

> *Anxiety effectively arises from those transformations that provoke a break within the rhythms of everyday life, making the old habitual gestures useless.*[34]
>
> Gilbert Simondon

Bertrand Gille's 'technical system' names the historio-cultural interplay between technology and society, where the evolution of certain technologies are brought about through particular inventions, interdependencies, and acquisitions; and technical systems only become *proper* technical systems when they achieve states of equilibrium. Shifts in technical systems have traditionally been characterised by gradual evolution, which afforded extended periods of familiarisation and repeated opportunities for measured adjustments and cultural stabilisation.[35] Fernand Braudel describes a typical instance of the complicated and drawn out process of adaptation – the scythe; although the persistent image of *Schnitter Tod* (death armed with a scythe) was present from the fourteenth century onward, it was not until the beginning of the nineteenth century that the scythe finally supplanted the sickle as the primary harvester's implement.[36]

A key challenge to technical progress is that 'transformations of the technical system regularly bring in their wake upheavals of the social system.'[37] Here, Gilles is pointing to the way an emergent technical individual can be both transformational and adversarial; for example, Braudel describes outrage in 1669 when, 'a stagecoach covered the distance from Manchester to London in a day.' This transformational agent signalled for many the destruction of an era; or as Braudel says, 'it was the end of the noble art of horsemanship; it spelled ruination for saddle and spur manufacturers; it meant the disappearance of the Thames boatmen.'[38]

Although some of these fears seem completely nonsensical to modern eyes, the iron grip of nostalgia can be powerful. One of the most frightening and tragic instances of nostalgic shortsightedness in history is found in a pre-First World War British military training manual that states, 'it must be accepted as a principle that the rifle, effective as it is, cannot replace the effect produced by the speed of the horse, the magnetism

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2 Reaseach assistant Skyler Howell shows a Techno-log coming out of its mould.

3

of the charge, and the terror of cold steel.'[39] Such romantic reverie led the British military to regard guns as a minor technical improvement, 'twentieth-century spears', rather than transformational agent. [40] As a result, no tactics or training were developed or practiced, leading to a grim climax at the Somme,[41] with 60,000 formation-bound British troops 'strolling exposed in neat lines [...] (carrying) rifles across their chests, in the drill-field posture known as port arms', into the teeth of entrenched German automatic weapons.[42]

To understand the resistance to technological change, it is important to appreciate the cultural interplay between the technical object and its associated milieu. The technical object as *element* indicates an artisanal enhancement that does not lead to any upset or anxiety in a culture. The technical object as *individual* marks a stage of evolution where the technological object becomes potentially adversarial, especially if it significantly transforms the role of the human being in the milieu, as Simondon notes:

> *The notion of technical evolution is altered in the 19th century with the birth of the complete technical individual. As long as these individuals only replace animals, the disturbances are not a source of frustration. The steam engine replaces the horse to draw wagons and it powers spinning mills. Human actions are modified somewhat but man is not replaced as long as the machine only brings on a wider use of energy sources.*[43]

The rapid proliferation of new technical systems after the industrial revolution means that technical systems become increasingly characterised by *decreasing* periods of stabilisation. Simondon was concerned by the increased speed of upheaval, noting, 'too rapid change works against technical progress because it interferes with the transmission of what one age bequeaths to the next in the form of technical elements.'[44] Bernard Stiegler sees the emergent state of 'permanent innovation' destroying 'the rhythms of cultural evolution and the rhythms of technical evolution'. Or as he succinctly states, 'technics evolves more quickly than culture.'[45]

Simondon believes that recovering productive thinking about this tenuous situation begins with a particular focus on the *technical elements*.[46] The reason that he believes this focus is important is because attending to the transition from *element* to *individual* is the means to understand the 'serrated evolution', or 'solidarity of succession', of technical evolution.[47] Which is to say, it is in the phase before becoming a destabilising individual that enhancements and impacts of the element can be studied and tested, the process of concretisation can be furthered with prognostications and protocols for incorporation into a milieu to increase the chances of stabilisation.[48] So, for example, when in 1928, Skilsaw produces their Model E, which finds a level of concretisation in the 1937 Model 77, carpenters can benefit from this *element* which maximises the energy expenditure of the carpenter (who otherwise would need to saw boards) and decreases the time needed to process lumber for construction. Here, human power is replaced and thus work is both easier and more precise because of the efficiency gained:

> *When man, while preserving the fruit of his training, exchanges an old tool for a new tool whose manipulation is the same, he has the feeling of having more precise, skillful, and rapid gestures; it is the entire corporeal schema that expands against his limitations, that dilates and frees itself; the impression of awkwardness diminishes: the trained man feels more skillful with a better tool; he has greater self-confidence; for the tool is an extension of the organ, and is carried by the gesture.*[49]

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Interestingly, it seems that most of current construction is still unaffected by the next step in the progression of the technical individual. Here, 'man's frustrations begin when the machine replaces man: automatic weaving looms, forging presses, machinery in the new factories.'[50] Even 3D printing in architecture is currently operating at the level of technical element – it is a tool in the larger more established milieu of construction. Undoubtedly, the industry has a way to go before arriving at a *truly* 3D-printed house; however, if 3D printing becomes a technical individual as described above there will be great anxiety and resistance as traditions and trades become modalities of the past.

Printimer: a serrated evolution

An obstacle should become a means of achievement.[51]
Gilbert Simondon

In all of what has been discussed one thing is apparent – it is not up to the inventor whether a technological innovation creates a new technical system or a new majoritarian way of doing something, this is why Simondon urged a study of elements on their way to becoming individuals – he called key evolutionary moments in these transitional states 'inflexion points'.

So, what are the inflexion points for P_T? Although P_T has always operated under the auspices of additive manufacturing, the reality is that P_T has always had a mixed identity: it has aimed to utilise waste, it has aimed to engage with modular construction (at the level of a SIP), it has aimed to leverage AM techniques, and it has aimed at non-toxic binding agents. Thus, a challenge for P_T is to decide if it has a singular technical essence or should endeavour to affect several possible outcomes. Regardless, it is safe to say that the inflexion points for P_T lie in the places where AEC falls short under the heading of resiliency: the wasting of resources, toxicity of products, shortages of skilled labour, inefficiencies in construction, and the unreliability of supply chains. That said, the progress of P_T has been (and will be) shaped by the realities of the world and the limits of technological development; thus, in the spirit of the epigraph that began this section, we have tried to view these setbacks not as limits and obstacles, but rather as inception points for creative evolution.

Starting out, the issues of 'printing panels' – both in terms of tensile strength and manufacturing inefficiencies – led to a sense of clarity about the problems of this approach. It also led to the thinking of other avenues that were not apparent at the commencement of the project. In light of the panel 'setback', there was a gradual shift (in group acceptance) from a 'SIP model' towards what we have called the 'Icon model', which is to say – 3D printing of a building on site. In making this move, we alleviated some of the tensile strength concerns (by placing the material more generally in compression), but we were still mired in the relatively primitive nature of the printing apparatus. For several years the print contraption has been slow and imprecise (imprecise in the context of 3D printing means that it doesn't have the capacity to do the complexity that, say, PVA printing does). Facing these limitations, we acknowledged that we were not fully leveraging the medium of 3D printing in terms of exactness (seen at the smaller scales of printing) and in terms of production output (seen in larger-scale concrete printing). In considering these deficiencies as prompts to another new round of thinking, we began to imagine outcomes that focused on the material itself – applications that went outside of the bounds of 3D printing.

As suggested of the switch from SIP to Icon, such pivots do not happen easily for linear thinkers and particularly ones working on science grants. Thus, given that our grant title is '*Developing a Circular Bio-Based Framework For Architecture, Engineering and Construction Through Additive Manufacturing*', there were many discussions where team members felt we could not try anything that was not 3D printing because we had promised 3D printing in the proposal. Yet, the world of invention is an endless trove of stories where the failure to realise an initial intention yielded a better result – if Walter Jeager had thrown away his 'smoke detector' because it failed to do what he intended (detect poison gas), then he would have denied a critical inflexion point; such unexpected outcomes constantly arise through a vital creative process.

A large part of architectural education is teaching students to attune themselves to these uncertainties and fold them into new understandings. As part of the P_T grant, we have asked this question explicitly, prompting graduate researchers to imagine other possible deployments of the P_T material. In one semester, two of our research assistants played out a scenario that was not printing but extrusion (acknowledging the current lack of capacity in our production process) *[1]*. It paired this lower technological method with imagining higher level control and delivery system technologies – in essence working from a stick framing model with the idea that instead of cutting wood to length, one could simply extrude the wood to length (thus eliminating waste) and couple this with a means of creating and storing batches of wood and then distributing and constructing the project using drones (building off some of the drone-weaving work of Gramazio Kohler Research).[52]

A focus of our current work was spawned by attempting to address the limited tensile capacities of the *wood flour*. The design team asked what it might look like to lean into what the material currently does well: it is good in compression, it leverages waste, and it is fire resistant. With these factors in mind, we conceived of the 'Techno-log'. *[2, 3]*. Techno-log is also considered as a means to promoting a sustainable material that might be more widely accepted (as a technical element) into

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the current modalities of building, enhancing current practices as opposed to transforming them fundamentally. The techno-log also leverages a low-tech approach to the material, which allows us to be less selective in the quality of the sawdust (i.e., the wood flour doesn't need to be nearly as fine for a log because the log is being hydraulically pressed into shape). The idea here is to build something akin to a traditional Scandinavian log home. The logs are keyed top and bottom and are meant to be deployable as a building material with properties that allow it to function within the current milieu, that is to say, it can be cut on a chop saw, shot with a pneumatic nail gun and driven with a screwdriver. Conceptually it is the opposite of the AM focus, which requires a paradigm shift. The techno-log on the other hand can insert itself into current practices by only having aspects of proprietary unfamiliarity, but otherwise can be incorporated it into more typical residential building practices in the United States. The beauty of technology is that it is a both / and proposal, because it also offers us a means to build analogue, what we envision the printer might be able to do in the future. In other words, we can deploy this novel material into typical construction scenarios, subject it to the elements and forces of nature, the abuses of users, and the techniques of builders as a low-cost investment into material performance that is not bound to labs and simulations and the limitations of current printing capabilities.

Another articulation of the P_T essence could be in truly moving the architect into the position of conductor with a direct interface between the design and the construction process. This scenario certainly has potential within the territory being forged in current AM efforts, which, in the residential sector, already point to reductions in time, materials, cost, waste, and carbon emissions. This is occurring despite the majority of all building-scale 3D printing still relying upon a major carbon offender and non-renewable material – concrete.[53] So there is one scenario where P_T focuses on a number of smaller focused breakthroughs – from bio-resin performance, to the machining of diverse high-function nozzles for the printer, to the streamlining of supply logistics, to the crafting of seamless user interfaces – in order to affect the already emerging AM industry via the option of a low carbon, arguably circular, construction material. Another avenue for P_T could be at the level of the mixture itself, reconstituting various materials through different 'recipes' that achieve different performances. For example, mixing wood-based aerogel for increased thermal resistance; weaving in hemp fibers to improve tensile strength.

A major point of these speculative constructions has been to make ascendant the continual questioning of assumed limits, boundaries, and truths that can become entrenched when working on this sort of project. In this way, we keep our eye on both our expectations and allow for unexpected alternatives and variations.

Temporary conclusions

> *The artisan's representation is engulfed in the concrete, engaged in material manipulation and sensible existence it is dominated by its object. On the other hand, the engineer's representation is dominating: it makes out of the object a bundle of measured relations, a product, an ensemble of characteristic* [54]
>
> Gilbert Simondon

Although architecture is fundamentally interdisciplinary, and architects are trained to synthesise the endeavours of partners and sub-teams, our current work pushes the necessity of the interdisciplinary collaboration to the next level and in a way fundamentally different to what interdisciplinarity has meant to architecture in the past. It is not the collaborations we are used to with structural engineers, landscape architects, interior designers, and other building consultants; it is now acknowledging that as architects we do not have the training to make bio-resins, we cannot fabricate 3D printers, we have no basis from which to understand the long-term performance implications of novel materials, we are unprepared to understand and manipulate the structural properties and behaviors of artefacts created by AM machinery. In short, this work goes nowhere in architecture without a massive amount of specialised expertise, a huge amount of learning, and unending communication.

However, in all of this, architectural implementation is tantamount – the project is technical, spatial, aesthetic, social. Keeping this architectural agenda in focus requires a complicated dialogue between many people with different investments. In particular, the makeup of our research team, which is mostly composed of scientists and engineers, complicates this communication in that many amongst them want to figure things out in the abstract as a kind of feasibility *apriori*, treat intention as gold, experimental testing as an end itself, and forget 'why'.

In light of these drives and preoccupations, there is a real need for us to vouchsafe design thinking and the technical from the scientific and machinic, which means seeking the technical essence through implementability using both design *and* build as methodology. That is, we see ourselves in the holistic realm Simondon deems 'the aesthetic', which aims to understand the technical from the midst of the technical milieu and enmeshed with the environment, endeavouring to search for future unity.[55] It is from this position that we become actors who attempt to pose advantageous assemblages (design) and create artisanal feedback through the deployment material instantiations that facilitate PrinTimber's implementation wholistically. The latter provides perspective on the utility, the weight, the workability, and ultimately the durability when P_T is utilised in a

https://doi.org/10.1017/S1359135525100791 Published online by Cambridge University Press

construction environment, providing direct comparisons with other possible ways of building.

In a situation where one aims to deliver not merely an 'incremental improvement' but rather, affect the technical ensemble as a whole, one cannot produce *just* a bio-resin, or a machine that prints *wood flour*, or a new composite material. One must understand how they all work in concert to produce novel architectural formations – in our case breakthroughs in our thinking about housing – that can gain sophistication and acceptance, and how the process of concretisation itself can be catalysed. Concretisation is necessarily folded into the problematic; it means all ends are open-ended. It could mean an assortment of print media deployed via combinations of nozzles and conveyances that turn housebuilding – from foundations to roofs, to windows, doors and beyond – into a one-person, single-process endeavour. This may perhaps be a bit far-fetched, but one thing is clear, we should not eliminate this as a viable option simply because it seems unsolvable; rather, such insolvability is often the very impetus to breakthrough into new possibilities. If nothing else, the fundamental complexity of the proposition, demands that any achievement or advance that comes from our research will depend on contact with other multidisciplinary teams working in areas tangential to ours: perhaps a robotic jammed structures[56] team[57] develops a building foundation, without Portland cement, that can easily be removed and redeployed. Although the specific criteria for advancement are currently murky, one thing is clear: just as the platform framing is not possible without the balloon framing, P_T is not possible without the *COBODs*, *Peris*, *Icons*, and *Winsuns* of this world. Hopefully it follows that a future home made from wood waste is made possible by the work of P_T.[58]

Notes

1. Gilbert Simondon, *On the Mode of Existence of Technical Objects*, trans. by Cecile Malaspina and John Rogove (Minneapolis, MN: Univocal, 2017), pp. 87–8.
2. Our group is organised into four teams: the Resin Team, the Print Team, the Performance Team, and the Design Team. The source material for the project is the sweepings of one of our local sawmill's floor, which is then sifted, sorted, and ground into a wood flour by the Print Team. The Print Team has also undertaken the construction of a print system that allows us to produce prototypes of the printed material; they developed a working printer during the first year of the grant and have since developed several improved versions, which have proven both faster and more powerful (can move a greater volume of material). The Resin Team is tasked with developing a bio-based (non-formaldehyde) resin to be the primary binder of the wood flour (in current prototyping, the wood flour is being printed using a sodium silicate solution). Going forward the idea is that using oils extracted from different species of wood, the Resin Team will chemically construct this bio-based binding agent. The Performance Team addresses the structural, mechanical, and weathering analysis of the printed output. And we, the Design Team, are focused on aspirational speculations, near future constructions in search of possible utilisation of the material in architectural applications with a primary emphasis on affordable housing.
3. This project began as one of the initial investigator's architectural Master's thesis from 1984 with the notion of creating a wood-based method for 3D printing a SIP-like panel, wherein all openings for doors and windows and chases for electrical, plumbing, and mechanical would be printed as part of the making of the panel. This basic idea was the starting point for writing the P_T grant.
4. In fact, one of the members of our advisory board, a president of a plywood company, explicitly critiqued the panel direction for this very reason.
5. Simondon, *On the Mode of Existence of Technical Objects*, p. 105.
6. To be fair, it is hard to place a house in the same terms as an engine; an engine has a singular purpose, a house fulfills a multitude of purposes; the parts of an engine become strategically fused to form a relatively inseparable complexity, a house remains a taxonomy of discrete components; an engine is tied to the labs and factories that support science and engineering; the house is clearly tied to the artisanal milieux of contractors and builders.
7. Bernard Stiegler, *Technics and Time 1: The Fault of Epimetheus*, trans. by Stephen Barker (Stanford, CA: Stanford University Press 1998), p. 59. For example: all gastropods have twisting shells, all hatchets have handles, all arrows are balanced at a point along one-third of their length)
8. All the components for a stick-built home are always on hand and readily available at any home improvement store.
9. Simondon, *On the Mode of Existence of Technical Objects*, p. 124.
10. Ibid., p. 27.
11. Ibid.
12. Ibid., p. 30.
13. Ibid., p. 18.
14. Ibid., p. 21.
15. Ibid., p. 30.
16. Ibid., p. 109.
17. Home Depot points to both the specific chain of 'big box stores' that are pervasive across the US as well as the more general DYI culture that has, via various home improvement outlets, empowered homeowners to take on additions, remodels, and upgrades to their homes with little to no professional assistance.
18. 'Perm rating' speaks to the water/vapor permeability of a building material, 0= impermeable; R-value is the standard US insulation value, 0= no insulative value; Janka is a wood hardness test, which reaches the force required to press half the diameter of a .444" steel ball into a piece of wood (1450 is the hardness rating for hard maple); STC rating measures how well a building material or assembly reduces airborne sound; NRC is noise reduction coefficient – 0: the material reflects all sound, 1: the material absorbs all sound.
19. From COBOD International A/S, 'The Truth: Facts about the True State of the Art of 3D Construction Technology' <chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://cobod.com/wp-content/uploads/2019/12/3DCP-fact-sheet-Final.pdf> (accessed 16 January 2023).
20. Icon and Apsis Cor can do foundations, currently only

https://doi.org/10.1017/S1359135525100791 Published online by Cambridge University Press

Armatron can do foundations and roofs … however, unlike Icon and Apsis, they have no full-scale built work to date.

21. For example, Contour-Craft; also Mighty Buildings, the company that is undertaking a highly touted development of 3D-printed Net zero houses outside Palm Springs, is working from modular panels that have only a portion that are 3D printed. <https://www.cnn.com/2021/03/18/business/california-3d-printed-neighborhood-trnd/index.html>; <https://www.mightybuildings.com/mighty-kit-system> (accessed 29 October 2024).
22. One of the more advanced in terms of integration is the TECLA House developed by Mario Cucinella Architects and WASP as an explorative research endeavour. Deploying a local material (raw earth) and making use of the material optimisation opportunities provided by parametric and 3D printing technologies. Instead of the 'solid wall' typically associated with vernacular construction using earth (e.g., rammed earth), this approach makes use of the advantages of a webbed infill enhancing the cross section structural capabilities with the use of less material. This also leaves channels free for insulation, systems, and ventilation, and explores a structural system (Dome) traditionally associated with materials that work well in compression that will solve both wall and roof requirements, aiming at 'optimization of the infill based on the humidity and temperature values'. In reference to a diagram comparing infill configurations in three case studies by SOS (Partnership with Mario Cucinella Architects in 'TECLA – Technology and Clay: The First Eco-Sustainable Housing Model 3D Printed from Raw Earth' by Mario Cucinella Architects <https://www.mcarchitects.it/en/projects/tecla-technology-and-clay> (accessed 23 February 2023).
23. Verzoni, Angelo, 'Printing Buildings', *NFPA Journal* (2020) <https://www.nfpa.org/News-and-Research/Publications-and-media/NFPA-Journal/2020/March-April-2020/Features/3D-Printing\> (accessed 13 October 2024).
24. Gilbert Simondon, *On the Mode of Existence of Technical Objects*, trans. by Ninian Mellamphy (Paris: Aubier, Editions Montaigne, 1980, 1958), p. 20.
25. Ibid., p. 19 <https://english.duke.edu/uploads/assets/Simondon_MEOT_part_1.pdf>.
26. Ibid., p. 43.
27. Ben Dreith, 'ICON and Lake Flato build 3D-printed House Zero in Austin', Dezeen, 4 March 2022 <https://www.dezeen.com/2022/03/04/icon-lake-flato-3d-printed-house-zero-austin> (accessed 13 February 2023).
28. Weijie Zhong, Torsten Schröder, Juliette Bekkering, 'Biophilic Design in Architecture and its Contributions to Health, Well-Being, and Sustainability: A Critical Review', *Frontiers of Architectural Research*, 11:1 (2022), 114–41 (p. 117), ISSN 2095-2635 <https://doi.org/10.1016/j.foar.2021.07.006>.
29. Ibid.
30. <https://www.roseburg.com/medium-density-fiberboard-mdf/armorite/>.
31. <https://www.glavel.com>.
32. Raymond Loewy, *Never Leave Well Enough Alone, New York* (London: Simon and Schuster, 1951), p. 277.
33. Interview with Mallory Buscemi, January 2022.
34 Simondon, *On the Mode of Existence of Technical Objects*, p. 130.
35 Stiegler, *Technics and Time 1: The Fault of Epimetheus*, pp. 29–32.
36 Fernand Braudel, *The Structures of Everyday Life: Civilization and Capitalism, 15th–18th Century, Volume 1* (New York, NY: Harper & Row 1982), p. 335.
37 Stiegler, *Technics and Time 1: The Fault of Epimetheus*, p. 15.
38 Braudel, *The Structures of Everyday Life: Civilization and Capitalism, 15th–18th Century Volume 1*, p. 425.
39 C. J. Chivers, *The Gun*, Kindle edn (London: Simon & Schuster, 2010), p. 113.
40 Ibid., p. 126.
41 'By one estimate, 30,000 British soldiers were killed or wounded in the first sixty minutes. The midday tally reached 50,000. By the end of the day, 21,000 British soldiers were dead, 35,000 wounded, and 600 more had been taken prisoner.' Ibid., p. 134.
42. Ibid., p. 132.
43. Simondon, *On the Mode of Existence of Technical Objects*, p. 115.
44. Ibid., p. 88.
45. Stiegler, *Technics and Time 1: The Fault of Epimetheus*, p. 15.
46. Simondon, *On the Mode of Existence of Technical Objects*, p. 66. He points out that one of the main differences is that the element has no associated milieu; thus, it might be compared to an organ in the body, suggesting an 'organology' as a direct study of technical elements.
47. Ibid., p. 68.
48. Ibid., p. 75.
49. Ibid., p. 130.
50. Ibid., pp. 115–16.
51. Ibid., p. 22.
52. Benedict Hobson, 'Drones can weave structures in space in just a few minutes', Dezeen, 4 March 2015 <https://www.dezeen.com/2015/03/04/movie-drones-architecture-weave-tensile-structures-ammar-mirjan-gramazio-kohler-research/>
53. Oscar Holand, 'World's Largest 3D-Printed Neighborhood to Break Ground in Texas', CNN <https://www.cnn.com/style/article/icon-3d-printed-homes-austin/index.html> (accessed November 2021).
54. Simondon, *On the Mode of Existence of Technical Objects*, pp. 87–8.
55. Ibid., p. 174.
56. 'Jamming' is a process wherein aggregate granular materials are compacted together to form a structural solid, which does not rely on any fasteners or adhesives and thus can be easily deconstructed.
57. For example: <https://gramaziokohler.arch.ethz.ch/web/e/forschung/275.html>.
58. This article is based on the first three years of a four-year award.

Data availability statement

The data that support the findings of this study are openly available from the sources cited below.

Illustration credits

arq gratefully acknowledges:
1 Amanda Eller and Skyler Howell
2 Skyler Howell
3 Robert Carne and Skyler Howell

Acknowledgements

The authors would like to acknowledge first the work of our faculty collaborators on the National Science Foundation Grant at both University of Idaho and Auburn University. We appreciate the tremendous effort they are committing to this project and the wealth of knowledge represented by this group. We would also like to acknowledge the numerous graduate students that move this work forward through their testing and evaluating various solutions within each of their disciplinary domains. This is truly a team effort.

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https://doi.org/10.1017/S1359135525100791 Published online by Cambridge University Press

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Competing interests
The author declares none.

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https://doi.org/10.1017/S1359135525100791 Published online by Cambridge University Press