Emergence and Architectural Engineering

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Following the ontological aspect of tacit knowing, Michael Polanyi sets our understanding of a comprehensive entity at two distinct levels, corresponding to the two terms of tacit knowing. In this framework, laws govern the particulars of an entity at the lower level, while principles govern the comprehensive entity at the higher level. This structure can be repeated to generate a hierarchical system where each level relies on the boundary conditions of the one below it (emergence), yet remains governed by its own higher-order logic. While Polanyi originally utilized the example of language — where the mechanics of phonetics serve the higher purpose of words and sentences, and so on — this same logic can be used to explore the built environment. By adopting this hierarchical lens — e.g., material > structural element > structure > building > neigbourhood — engineering pedagogy can train budding professionals to recognize the considerations that truly matter in large-scale projects. This perspective is critical for identifying and mitigating adverse heuristics — those rigid rules of thumb that are applicable for general cases but may lead to erroneous decisions when applied to a specific problem at hand. Shifting the focus from isolated calculations to the principles controlling the entity as a whole encourages a more resilient and reflective practice. This novel approach ensures that technical proficiency is balanced with an understanding of how individual components contribute to the integrity of the total system, ultimately improving the effectiveness of decision-making in the field.

Tacit Knowing

In his 1966 publication "The Tacit Dimension", Michael Polanyi presents his inquiry into personal knowledge through three essays; "tacit knowing", "emergence", and "a society of explorers." The discussion presented here draws primarily on the first two essays. In the book's introduction, Polanyi himself describes this work as "an *interim report* on an inquiry..." (Polanyi 1966).

Polanyi's study of tacit knowing stems from the observation that we can know more than we can tell. McCleary and Lazarus (1949) present an experiment where, during conditioning, the subjects are shown ten five-letter nonsense syllables and subjected to an electric shock after some of the nonsense syllables—*shock syllables*. In the testing that followed, the evidence suggests that the subjects were expecting a shock after the shock syllables were presented. Interestingly, when asked, they were not able to identify the shock syllables—they knew them only tacitly.

Polanyi presents the mechanism of tacit knowing as formed of two components: a proximal term and a distal term. In the above experiment, the shock-syllable is the proximal term, which the subject had an *awareness of*. The electric shock which followed the shock-syllable is the distal term, which the subject was *attending to*. Polanyi notes this as the functional relationship of tacit knowing: "we know the first term (i.e., proximal) only by relying on our awareness of it for attending to the second (i.e., distal)" (Polanyi, 1966).

Polanyi further identifies the phenomenal structure, semantic aspect, and ontological aspect of tacit knowing, describing how the two terms of tacit knowing interact. The ontological aspect is of interest to the discourse here: "we comprehend the entity by relying on our awareness of its particulars for attending to their joint meaning" (Polanyi, 1966). For instance, one recognises a familiar face by an *awareness of* the features of the face; but rather than matching each feature separately, the familiar face is *attended to* as a single coherent entity (i.e., joint meaning).

He further extends this idea by observing tools becoming extensions of ourselves. He illustrates it with the image of a blind man exploring a cave with a stick. The stick becomes an extension of himself—the awareness of the cave is his, not the stick's (Polanyi, 1966). Similarly, Polanyi thinks that scientists also *interiorize* the tools they use for scientific exploration and that scientific knowledge is the tool involved in the judgement of a scientist. Here, Polanyi brings the idea of indwelling. He suggests that we make the proximal term part of us in comprehending joint meaning. So, in the case of recognising a face, awareness is not merely *looking at*, but rather *dwelling in* the facial features.

Polanyi goes on to discuss what would happen if we closely scrutinise the particulars of which we have only tacit awareness. This will destroy – or *breakdown* – the joint meaning. A pianist playing a very familiar piece will temporarily lose track of it by trying to concentrate their attention on their fingers; but will get back on track by *attending to* the music (Polanyi 1966). Polanyi suggests (crucially) that this making good (or re-integration) after the temporary distraction "establishes a more secure and more accurate meaning of it."

The schematic in Figure 1 summarizes the above, also borrowing the terms 'intuitive' and 'effortful thinking' from Daniel Kahneman's two-system thinking (Kahneman, 2011) and 'breakdowns' to 'average everydayness' from Martin Heidegger. The figure illustrates how *breakdowns* introduced to *intuitive thinking* would cause *effortful thinking* and the understanding gained through the effortful thinking can be reintegrated into the intuitive thinking, resulting in a more secure and accurate intuition.

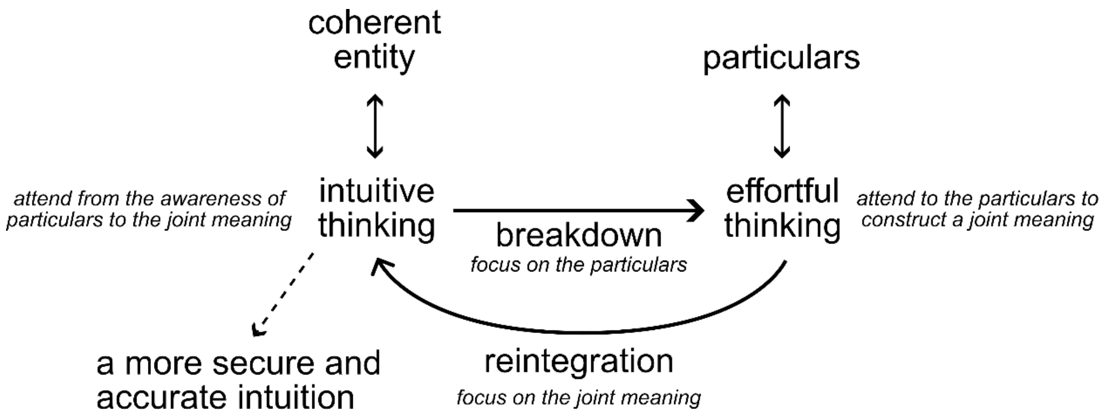
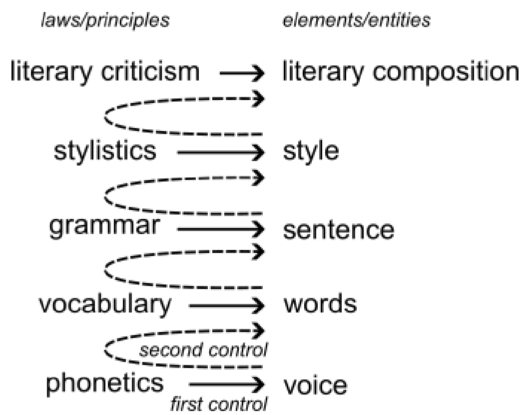


Figure 1 - Breakdowns introduced to intuitive thinking would cause effortful thinking. The understanding gained through the effortful thinking can be reintegrated into the intuitive thinking, resulting in a more secure and accurate intuition.

Emergence

Following the ontological aspect of tacit knowing, Polanyi sets our understanding of a comprehensive entity at two levels, also corresponding to the two terms of tacit knowing. There are laws governing the particulars of the entity at the lower level, and principles controlling the comprehensive entity at the higher level. This structure can be repeated to generate a hierarchical system, as shown in Figure 2.

This hierarchical system has interaction between two successive levels. The primary control is of the elements in a level by its laws: e.g., “voice controlled by phonetics” (see Figure 2). A secondary control exists, forming the interaction between the two levels (“marginal control”): e.g., “voice is shaped by vocabulary into meaningful words” (see Figure 2). Importantly, what this shows is that the principles on a higher level cannot be derived from the laws on the lower level: “the higher level only comes through a process not manifest in



the lower level” (Polanyi, 1966). This is Polanyi’s notion of emergence

Figure 2 - Hierarchical system of comprehensive entities, following Polanyi. Each pair consists of a lower level with laws governing the particulars (or elements) of the entity, and the upper level having principles controlling the comprehensive entity. Each pair has a first control of entities by their corresponding laws, and a second control of entities of a lower level being formed into the comprehensive entity.

Hierarchical structure for the built environment

The idea of emergence and marginal control presented by Polanyi using language as an example is extended in Figure 3 to the built environment: a setting where engineers, architects, and planners play a significant role.

At its most basic level, engineers and architects will deal with materials which is governed by their chemical composition (including physics at atomic levels). These basic materials are then formed to structural elements (e.g., a concrete beam, brick wall) with the use of technology (e.g., pre-cast concrete technology, brick laying techniques). And these structural elements are arranged in such a manner that we have a safe a liveable built environment.

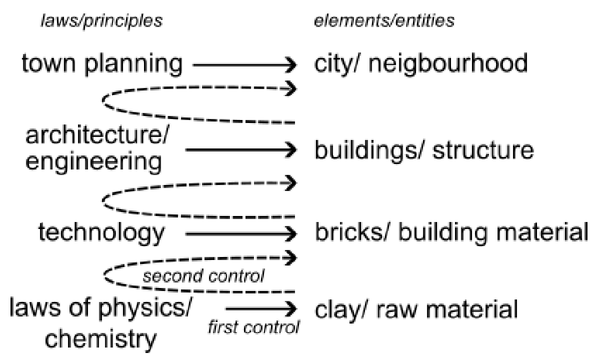


Figure *3* - Hierarchical system of comprehensive entities, following Polanyi, for the built environment.

Note that while the structural and architectural design (a higher level) is informed by the choice of materials and construction technologies at the lower level (e.g., the thermal capacity, safe clear spans), there are separate set of principles governing the higher level (e.g., human thermal comfort perception, lateral stability of the overall structure). This aligns with what Polanyi observed in the emergence structure.

The hierarchical structure can be used in engineering and architecture education, where a teacher guides the students. When one thinks intuitively, they think of a coherent entity, e.g., a structural element (see Figure 4) When breakdowns are introduced to force effortful thinking, they focus attention on the particulars (e.g., mechanics at the current hierarchical level, and material on the on below), which they were only aware of when they were tacitly thinking of the coherent entity. The breakdowns can be caused by either the teacher making probing questions or the student reflecting on their understanding of the coherent entity. However, to follow through with the breakdowns (and later to reintegrate), the student will require guidance from the teachers. The stage where an effortful exploration of particulars from technical know-how (i.e., heuristics founded on laws of physics) is done is where the teacher is engaged in teaching instructions, which can be a more passive exercise in the part of the student.

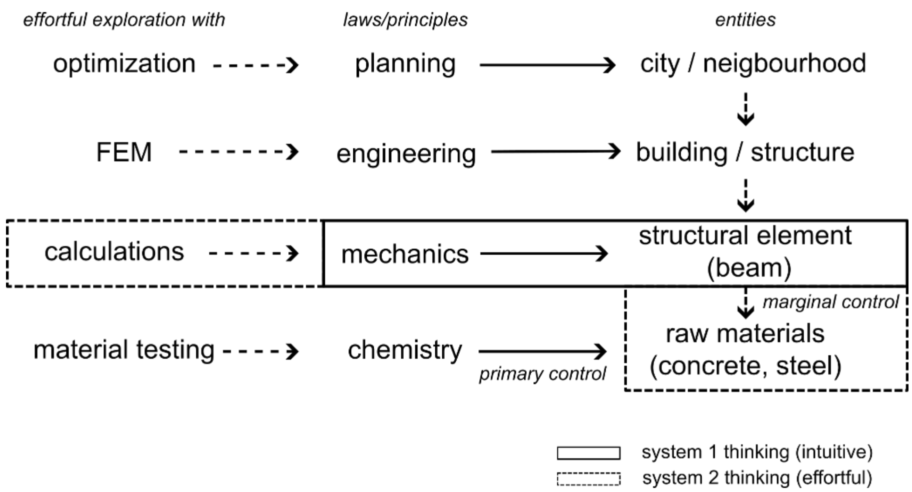


Figure 4 Hierarchical system of comprehensive entities, following Polanyi. Each entity consists of laws/principles that exercise primary control of the comprehensive entity at a given level, and marginal control of a lower-level entity in order to select the best configuration of those entities. The left-hand column identifies potential effortful thinking means to examine the laws/principles at each level.

Engineering Intuition

At this point, a note on heuristic is useful. While engineering and architecture is founded on physics and mathematics, a fair number of heuristics are used. When the science is either not definitive or too complex for the constraints of time and money, engineers will be called upon to make judgements. Those judgements will be guided by their professional and lived experiences. And those, while useful, might not always be correct or agree with the physics of the problem.

For instance, consider the physical property "strength". What strength means to a layperson on the one hand, and a civil or mechanical engineer on the other, could be significantly different. In the fable of the father, his sons, and the bundle of sticks, the bundle of sticks is understood by a layperson to be *stronger* (i.e., greater in strength) than a solitary stick. However, in engineering terms, the timber in both the bundle and the single stick would have the same material strength, allowing of course for the natural variability of such strength. What the layperson would call "stronger", is a difference in load-carrying capacity for an engineer.

The common language meaning, reinforced by stories and experiences, will be closer to the understanding of an engineer still in training, while the technical meaning might seem convoluted, nuanced, or even to constitute unnecessary detail. The lay understanding of strength, reinforced by stories and experiences, is second nature to us. It is only natural for one to replace the notion of "load-carrying capacity" with that of "strength". It is not common for such differences in meanings to get highlighted within engineering education.

The opportunity here is to get rid of the negative heuristics coming from experiences and socio-cultural influences, but to keep and reinforce those positive heuristics coming from the same sources. For instance, there might be cases when common knowledge trumps engineering knowledge. In designing a roof slab with only a service access, the engineering knowledge will tell one to use a lower design load matching the lower service life occupancy of the roof slab. However, your experiences might tell you that it is likely that this roof will be crowded, as this is a vantage point providing a view of a nearby popular sporting venue, therefore making a higher crowd load more appropriate. An engineer designing structures by his previous experience alone and another doing detailed calculations only are, on average, likely to be equally efficient (the former might save time, the latter might save material and arguably compromise on safety). One who can complement intuition with technical know-how (i.e., physics-based heuristics) is likely to be superior.

Exploring the hierarchical structure of built environment

The hierarchical structure of the built environment can be explored with probing questions to explore each level. Although a structural engineer may be operating at the level of structure and structural elements (see Figure 4), the hierarchy is chosen to have higher levels, to bring out a level that is much more familiar to a lay person (which an engineering student is when they start their engineering education). And, one level down from the structural element level is chosen, as that lower level forms the particulars to comprehend the structural elements as a coherent entity.

Let us consider a residential neighbourhood in an area affected by a tsunami. The placement and the nature of houses would have been decided by many factors including geography, local materials, as well as local culture, and the affluence of the community. In structural engineering terms, the important factors for an investigation include some of those parameters (e.g., geography, construction material, etc.,) and various other parameters too (e.g., the nature of the tsunami waves, shielding effect of vegetation, etc.,). A structural engineer interested in disaster management will be interested in this neighbourhood scale study employing tools such as Monte Carlo simulations to account for the variabilities of the parameters and make decisions to both prevent such disasters (e.g., vegetation growth, marking danger zones, recommending structural improvements) and assist with post-disaster recovery efforts. An example technical questions a structural engineer attempting to answer (and likely be asked) here is, "If 20ft tall tsunami hits this area, how many houses will be completely damaged?"

At a level lower, a structural engineer designing a building in a coastal zone susceptible to a tsunami will be interested in ensuring the safety of a particular building they charged with the design. They would be interested in parameters such as the likely inundation depth during a likely tsunami and the level of service required after such an event (e.g., schools and hospitals need to be functional immediately after a disaster). They will be interested in both placing the building safely and designing—choosing an appropriate construction material and a structural scheme (i.e., how to safely transfer the loads to ground). The fundamental question the structural engineer is attempting to answer here is, "What is the safest way to transfer the loading on the structure to the ground below?"

As a learning exercise, a different probing question can be made. "Will the structure still stand if a given wall is blown out due to the force of the tsunami wave?" When questioned, a student will likely give an intuitive answer. They can be then asked to explain their answer. This explanation does not have to be a physics-based one. It could be something, for instance, they know from experience: e.g., "the structure would stand after removal of the wall, because I remember seeing a house during construction which did not have infill walls and was still standing."

The teacher can guide the student to a more effortful exploration here. A load path diagram can be drawn and then checked if the load path would still exist after removing the wall in question. This is the effortful process of investigation here. If that evidence supports the intuitive answer of the student, their heuristic for intuition is beneficial, otherwise adverse.

However, the student's explanation may be valid only in limited cases. For instance, in this case, the structural type matters (e.g., a framed structure where the walls are not load-bearing versus load-bearing masonry structure). This now is a lesson in conceptual structural design (i.e., coming up with safe load paths), but instead of being a passive receiver of instructions the student and their experience is centre stage and developing their engineering intuition is the objective. Once trained adequately, the engineer would not need to draw a conceptual load path diagram, but just looking at the structure they would be able to visualize the load path, taking in visual clues, their learned knowledge, and professional experience.

At the level of structural element, the enquiry is into if this structural element will fail. This level would heavily involve calculations but also include simplifying assumptions on the material behaviour and loading. As such a parametric study could complement the effortful calculation to build an engineering heuristic. For instance, a beam of such and such span and height could safely withstand the loading from a residential building. While cases with extreme spans or extreme loading would require an effortful exercise, a heuristic can be built for the typical cases.

Furthermore, the structural system is only safe when the structural elements are themselves safe (the emergence). The learning can be closed with tying the learnings from the effortful exploration of the design of the structural element to the safety of the structural system. In our example, the students learning to design load-bearing masonry walls can now look at the whole structure subjected to a tsunami wave load and ask the question “will the tsunami wave blow out the wall in the first place?” Now, this may be an extreme case not covered by their typical calculations allowing them to note the limitations of the typical calculation.

A learning experience structured in this manner not only put the students experience and skills at the centre but also would bring into focus the uncertainties the engineer has to deal in design. Traditional lessons focused on calculations may give a sense of definitiveness of their designs when such is not present (particularly so when the validity of assumptions underlying those calculations are not honestly discussed).

It should be noted that the built environment is not a single stack of hierarchy as presented in this example. They are rather an interconnected set of hierarchies. For instance, a building will consist of more than its structure (and structural principles). Similarly, the structural engineer would not need the whole set of material laws known to humankind. For this example, and an engineering lesson, it might be useful to consider a simplified hierarchy as presented here.

In the case of an engineer-in-training, this process will invariably need to be guided by a teacher, specifically so in the case of instructions on using physics-based heuristics to investigate the particulars of a coherent entity. In the case of a more experienced engineer, the same process can start from a point of reflection and be self-guided in the effortful investigation of the particulars.

Conclusion

Michael Polanyi, noting that we know more than we can tell, introduces the concept of tacit knowing. He describes tacit knowing as a process involving a proximal term, of which we have an *awareness of*, and a distal term, which we *attend to*—"we comprehend the entity by relying on our awareness of its particulars for attending to their joint meaning". By organising such comprehended entities into hierarchical levels of integration, Polanyi further develops the concept of of emergence, whereby higher order entities arise form, yet cannot be fully reduced to, their constituent particulars

This paper extends these ideas to the built environment, proposing a framework through which engineering and architecture can be understood as hierarchically ordered systems. Within this framework, the built environment is viewed as a series of emergent levels, each integrating and transcending the structures beneath it. The hierarchical perspective is then shown to complement an approach to engineering education that centres the student and their lived experience in the development of engineering heuristics—that is, tacit understandings grounded in both the laws of physics and practical experience.

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