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Tiered Modelling – A Solution to Hyper-Coherent Morphological Models?

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Abstract: Morphological models that comprise few constraints between parameter values are considered hyper-coherent. A high degree of coherence in a model can be a problem if it results in a large and unwieldy solution space. This paper explores a possible methodological approach to solve the problem of coherence in morphological models. The case in point is a study of Human Built Operational Environments – sometimes called megacities. Instead of analyzing the total morphological field in one comprehensive process, the analysis was split into two tiers. In the first tier the morphological field was broken down into three distinct analytical bins, and analyzed separately. In the second tier the analytic products were integrated into an aggregate morphological field that was highly constrained, thus producing a smaller and more orderly solution space.

Keywords: General Morphological Analysis, Typology Analysis, Megacities, Urban Operations

Introduction

How do we deal with morphological models that have few internal constraints? *Hyper-coherent* models exhibit no or only a few mutual constraints between parameter values and tend to produce a *solution space* that is only minimally compressed. A high degree of *coherence* in a morphological model does not need to be a problem in itself, as it may simply reflect the empirical fact that any solution within the scope of the model is possible. However, if the whole point of modelling is to reduce complexity and enhance clarity and understanding, the usefulness of morphological models, at least in part, rests on their faculty to produce clearly delineated concepts and categories.

To some extent this requires a reduction of the number of solutions – or *configurations* – found in the final solution space, as compared to the original – and messy – morphological field. Ideally a morphological model should exhibit clear connections between parameters and enable meaningful assessments of consistency between parameter values. However, this is not always the case. At times we may be confronted with more ambiguous model constructs that do not easily lend themselves to the standard morphological analytic protocol[1] – consequently, a more innovative methodological approach may turn out to be appropriate.

[1] The concept «standard morphological analytic protocol» is here used somewhat ironically, since such a protocol does not exist in a strict sense. However, we find the morphological credo of complete openness valid also when it comes to the application of modelling practices.

This paper discusses a possible methodological approach to tackle the problem of minimally constrained morphological models that produce large and unwieldy solution spaces. The case in point is a study of military operations in large urban environments – sometimes called "megacities".[2] The analysis sought to develop an exhaustive typology related to urban environments as operational spaces. The modelling problem encountered was characterized by a high degree of internal coherence in the model, thus producing a solution space only marginally constrained compared to the over-all morphological field. The approach that was eventually selected involved a tiered analytic process developed in two stages. In the first stage the original morphological field was broken down into smaller sub-fields in order to produce new abstract concepts. In the second stage those abstract concepts where fused into an aggregate morphological field enabling the classification of the object of study into an all-encompassing typology. The remainder of this paper will briefly present some fundamental concepts of General Morphological Analysis (GMA). In the next section the modelling problem is characterized, and finally the tiered analytic approach, as well as the final conceptual construct, is described.

General Morphological Analysis – analysis of complex problem spaces

General Morphological Analysis is essentially a method for modelling of non-quantifiable, non-reducible, complex problem spaces. As opposed to traditional reductionist causal modelling, the method seeks to identify and investigate the entire set of relationships, or *configurations*, contained within any given problem space. In this sense, the method is closely related to typology analysis.[3] In contrast to some classification techniques in the social sciences, the morphological process, however, does not make any theoretical claims or purport to explain a given phenomenon in cause-and-effect terms.[4] The only information one can extract from the morphological process is whether a given solution is consistent or not, i.e. whether it relates to something that may exist in the real world.

Morphological analysis seeks to find solutions to problems, even when those problems are difficult to grasp or to delineate – i.e. when they are *wicked problems*.[5] The analytic process therefore begins by breaking the issue down into smaller components. Each component is characterized by one or more parameters. The components are then reassembled into a parameter set that encompasses the entire problem. Each parameter must be precisely defined, and an exhaustive and mutually excluding set of possible states, or *values*, pertaining to each parameter, has to be decided.

[2] Leo Blanken, Robert Burks, Iver Johansen, 2017. «Understanding Human Built Operational Environments». The study is under publication as a Naval Postgraduate School (NPS)/Norwegian Defence Research Establishment (FFI) Report.

[3] Ritchey, T. 1998. "General Morphological Analysis * A General Method for Non-Quantified Modelling." *Swedish Morphological Society, p. 3*.

[4] On the use of explanatory typologies, see: Elman, Colin. 2005. "Explanatory Typologies in Qualitative Studies of International Politics." *International Organization* 59 (2): 293–326. http://www.jstor.org/stable/3877906.

[5] Ritchey, T., 2013. "Wicked Problems: Modelling Social Messes with Morphological Analysis." *Acta Morphologica Generalis AMG* 2 (1). http://www.swemorph.com/pdf/wp.pdf. Rittel, Horst W. J., and Melvin M. Webber. 1973. "Dilemmas in General Theory and Planning." *Policy Science, Elsevier Publishing Company*, no. 4: 155–69. http://www.cc.gatech.edu/fac/ellendo/rittel/rittel-dilemma.pdf.

PARAMETER A	PARAMETER B	PARAMETER C	PARAMETER D
A1	B1	C1	D1
A2	B2	C2	D2
A3	B3	C3	D3
	B4	C4	D4
		C5	

Table 1: Multidimensional Matrix. Shaded cells constitute one solution.

Parameters and their values can be presented in a table with the parameters in the top row and the associated values in columns beneath each parameter, as shown in Table 1.

The matrix shown in Table 1 contains four parameters with the number of values attached to each parameter varying from three (Parameter A) to five (Parameter C). The total number of configurations, or theoretically possible *solutions*, in this matrix is 3 * 4 * 5 * 4 = 240. A solution can be defined as a *shape* consisting of one value on each parameter. In the example matrix, the shaded cells represent one of 240 possible solutions.

The main goal of the morphological process is a reduction of complexity. This is achieved when a potentially very large and complex morphological field, or *problem space*, is reduced to a smaller and more manageable *solution space*. In contrast to the morphological field, the solution space consists of only those configurations that can be considered possible, or internally consistent.

To enable the synthesis of a solution space, the model parameters need to be internally connected, i.e. any given parameter has to impose constraints on at least one other parameter in the model. A measure of connectivity is the degree to which pairs of values in the model are incompatible. When a large morphological field produces a relatively small solution space – i.e. when the ratio of the number of configurations in the solution space to the number of configurations in the morphological field is low – the model is *hyper-constrained*. And vice-versa, when the number of configurations in the solution space is not significantly reduced compared to the total morphological field, the model is *hyper-coherent*.[6] In practice, ratios in the order of 1–10 percent – which is not uncommon in morphological modelling – would imply a low degree of coherence, whereas ratios substantially above the 10 percent mark denote a high-coherence model.

[6] Ritchey, T. 2012. "On the Formal Properties of Morphological Models." *Acta Morphologica Generalis AMG* 1 (2). http://www.amg.swemorph.com/pdf/amg-1-2-2012.pdf. Ritchey, T. 2015. "Principles of Cross-Consistency Assessment in General Morphological Modelling." *Acta Morphologica Generalis* 4 (2).

Connectedness in a model is established in conjunction with the pairwise *cross-consistency assessment*. The assessment of consistency is based on two main criteria: First, *internal* consistency, i.e. whether a given value pair can be assessed as either consistent or non-consistent on purely logical grounds and, second, *external* (or *empirical*) consistency. The latter implies an assessment as to whether any given value pair conforms to or contradicts what may be considered empirically plausible.

In practice, the cross-consistency assessment is carried out by systematically working through the entire matrix, assessing the consistency of each and every value pair. The consistency matrix positions parameter values against each other in a pair-wise manner (see Table 3). For each value pair, a judgement is made as to whether the values can coexist according to the criteria of internal and external consistency. This judgement does not consider direction or causality, since causal modelling is not applied in morphological analysis.

The resulting *solution space* can be seen as a conceptual "map" that aids the discovery and identification of new relationships and configurations as well as encouraging investigation of boundary conditions. In addition, a vital part of the examination of the model output is to provide explanation – or "meaning" – to the morphological structure in terms of textual descriptions, images or other means for communication and cognizance.

Understanding Human Built Operational Environments (HBOEs)

Military operations in large and complex urban environments have taken on increasing significance as a function of three developments – (i) increasing urban populations, (ii) transparency and media scrutiny constraining operational rules of engagement, and (iii) contested legitimacy that can weaken the ability of state authorities to control political outcomes within their own cities.

While not aiming for a substantive analysis of urban operations as such, the main purpose of the HBOE study was to provide a "typological schema designed to assist in analyzing and planning current and future urban operations."[7] In doing so, the study also aimed to provide "a transparent and flexible methodology […] for planners and analysts to utilize at varied levels of detail".[8]

In order to organize this vast and complex issue into a clear conceptual construct, three overarching dimensions were identified, (i) *the physical dimension*: the material attributes of the urban environment; (ii) *the human dimension*: the human terrain laid on top of the material landscape; and (iii) *the mission dimension*: the nature of foreign military forces' interaction with the city.[9]

These three overarching dimensions contain within themselves a number of sub-dimensions. Hence, the next step in the analysis consisted in further refining those dimensions into a workable parameter set to be taken into the morphological analysis.

[7] Blanken et al., 2017, p. 1.
[8] Ibid, p. 1.
[9] Ibid, p. 19.

For the *physical dimension* the focus turned to factors affecting the flow of people, resources, and information into, out of, and within the city. Characterizing the physical and material aspects of the urban landscape and its surroundings, two sub-components were defined: *external access* and *internal access*.

External access describes the accessibility of the city seen from the viewpoint of an intervening military force. Here, a continuum of external natural and man-made features is simply dichotomized into two possible states: *high/low*.

Internal access encompasses all aspects of movement within the city itself. Again a multiplicity of factors like city size and infrastructure development is subsumed into a simple dichotomy of *high/low*.

For the *human dimension* three sub-components were defined: *demographics, social expectations*, and *governance*. The *demographics* of a city are characterized by the city's population – its size, density, ethnic composition etc. For the purposes of the morphological analysis this parameter, however, is simply subdivided into the readily quantifiable dichotomy of *large* and *small*.

Next, the social dynamic of the city is captured by turning to the most basic aspects of social life, i.e. the degree to which the city meets the social expectations of its inhabitants. Referring to established theory of revolutions, specifically the "Davis J-curve theory"[10], this sub-component is divided into *social expectations met* or *not met*.

Lastly, *governance* is primarily relevant as a measure of the different partnering options for an intervening foreign military force in a city. Here, three possible conditions stand out as particularly relevant: (i) *formal partner*: the internationally recognized authorities of the state; (ii) *expedient partner*: actors that can claim legitimacy from (parts of) the population but who do not have international (external) recognition; and (iii) in cases where no formal or expedient partner is available or a potential partner is not acceptable, we have the *no partner* option.

The *mission dimension* seeks to capture the nature of the military interaction with the urban environment through a trichotomy of varying degrees of kinetic combat; *high kinetic conflict*, *low kinetic conflict* and *non-kinetic operations*.

The Morphological Model of HBOEs

Now that the three core dimensions and their subcomponents are defined, we can construct the multidimensional matrix that contains the entire morphological space of our research problem: megacities as operational spaces.

Table 2 presents the core dimensions in the top row, and then the subcomponents associated with each core dimension in the second row. The subcomponents constitute the *parameters* that go into the morphological analysis. Each parameter is defined by a set of *values* – or conditions – that are listed in columns under each parameter.

[10] Davis, James C. 1962. «Toward a theory of Revolution», American Sociological review 27 (1), 5-19.

CORE DIMENSIONS	Physical		Human			Mission
PARAMETERS	Internal Access	External Access	Demography	Social Expectations	Governance	Mission
VALUES	High Internal Access	High External Access	Large	Met	Formal Partner	Non Kinetic
	Low Internal Access	Low External Access	Small	Not Met	Expedient Partner	Low Kinetic
					No Partner	High Intensity

Table 2: Morphological field of megacities as operational spaces

This morphological field consists of 2 * 2 * 2 * 2 * 3 * 3 = 144 different combinations of values. In theory this means that 144 unique *solutions*, or typological categories, are found within the problem space. It is the object of further analysis to weed out inconsistent solutions thus retaining only those solutions that are assessed to be consistent, and produce a viable conceptual construct for further analysis.

However, initial analysis indicates that here we might be confronted with a hyper-coherent morphological model. The cross-consistency assessment reveals very few – if any – clear constraints among the model's value pairs. Possible cases of inconsistent pairs may be related to different partnering options (*expedient partner, no partner*) and characteristics of the military operation (*non-kinetic*) and type of social expectations (*met/not met*), as shown in Table 3.

		Intern		Extern		Demo		Social		Governan		
		High Internal Access	Low Intinternal Access	High External Access	Low Extertnal Access	Large	Small	Met	Not Met	Formal Partner	Expedient Partner	No Partner
External Access	High External Access											
	Low Extertnal Access											
Demography	Large											
	Small											
Social Expectations	Met											
	Not Met											
Governance	Formal Partner											
	Expedient Partner							X				
	No Partner								X			
Mission	Non Kinetic										X	X
	Low Kinetic											
	High Intensity											

Table 3: Consistency matrix of megacities as operational spaces. "X" marks inconsistent value pairs.

Even with these constraints in place, the model still produces 80 consistent solutions, a ratio of 55,5 percent. What is more troublesome, however, is that there is no clear way to organize or further analyze the solution space to produce clear and consistent categories or *types*. A typology thus might end up either having too much diversity within each category, or having too many typological categories. Therefore, in order to simplify the analysis and to enhance clarity, a two-step approach to analysis was adopted.

The First Tier: Analyzing the Core Dimensions

In the first step, each of the core dimensions (PHYSICAL, HUMAN, MISSION) was analyzed separately. Hence, it was possible to create more meaningful, abstract concepts that could be taken into the second aggregate phase of the analysis. Then, in the next step, these concepts were fused into a second morphological field.

The Physical Dimension

The Physical dimension consists of two parameters – *internal access* and *external access* – each of which is characterized by two values – *high* and *low*.

Internal Access	External Access
High Internal Access	High External Access
Low Intinternal Access	Low Extertnal Access

Table 4: The physical dimension

Table 4 presents the morphological field of the physical dimension. Assessment of the interrelationships between the parameters indicates that the field cannot be reduced. Hence, there are four possible outcomes:

1. High Internal Access – High External Access
2. Low Internal Access – High External Access
3. High Internal Access – Low External Access
4. Low Internal Access – Low External Access

The Human Dimension

The Human dimension consists of three parameters – Demography, Social Expectations, and Governance (Table 5).

For the *demography* parameter, two values are defined: *large* and *small*. The *social expectations* parameter also has two values: *met* and *not met*. For the governance parameter three values are defined: *formal partner*, *expedient partner*, and *no partner*. The morphological field of the Human dimension thus consists of 2 * 2 * 3 = 12 different configurations. A cross-consistency assessment is carried out in order to establish a consistent solution space.

Demography	Social Expectations	Governance
Large	Met	Formal Partner
Small	Not Met	Expedient Partner
		No Partner

Table 5: The human dimension

The cross-consistency assessment measures each value against every other value in the matrix in order to establish the consistency of value pairs and, consequently, of entire solutions. The consistency matrix is presented in Table 6.

		Demo		Social	
		Large	Small	Met	Not Met
Social Expectations	Met				
	Not Met				
Governance	Formal Partner				
	Expedient Partner			X	
	No Partner				X

Table 6: Consistency matrix of human dimension.

Two value pairs were assessed as being inconsistent (see Table 6).

- *SOCIAL EXPECTATIONS/met – GOVERNANCE/expedient partner*
- *SOCIAL EXPECTATIONS/ not met – GOVERNANCE/no partner*

The solution space of the human dimension thus consists of eight unique solutions which represent four “City Types” (Table 7). In the next step we will seek to compress this space further.

DEMOGRAPHY	SOCIAL EXPECTATIONS	GOVERNANCE	CITY TYPES
Large	Not Met	Expedient Partner	**Fragmented City**
Small	Not Met	Expedient Partner	
Large	Met	Formal Partner	**Functional City**
Small	Met	Formal Partner	
Large	Not Met	Formal Partner	**Revolutionary City**
Small	Not Met	Formal Partner	
Large	Met	No Partner	**Hostile City**
Small	Met	No Partner	

Table 7: Solution space for human dimension

The Mission Dimension

The core dimension *mission* only consists of one parameter. Hence, the three values that were defined above remain as the entire set of outcomes: 1) Non Kinetic; 2) Low Kinetic and 3) High Kinetic

The Second Tier: Analyzing the City as Operational Environment

We now turn to the aggregate analysis of cities as operational environments. For this analysis we fuse the analytic output of the three core dimensions into one morphological field (see Table 8).

PHYSICAL (Access)	HUMAN	MISSION
High Internal High External	Functional City	Non Kinetic
High Internal Low External	Fragmented City	Low Kinetic
Low Internal High External	Revolutionary City	High Kinetic
Low Internal Low External	Hostile City	

Table 8: Aggregate Analysis Morphological field

The problem space consists of 4 * 4 * 3 = 48 possible configurations. In order to determine a solution space, consisting only of solutions that are logically and empirically consistent, a cross-consistency assessment is again carried out (Table 9)

		PHYSICAL				HUMAN			
		High Internal High External	High Internal Low External	Low Internal High External	Low Internal Low External	Functional City	Fragmented City	Revolutionary City	Hostile City
HUMAN	Functional City			X	X				
	Fragmented City	X	X						
	Revolutionary City	X	X						
	Hostile City			X	X				
MISSION	Non Kinetic						X	X	X
	Low Kinetic					X			X
	High Kinetic					X	X	X	

Table 9: Cross-Consistency Matrix of Aggregate Analysis.

Altogether 16 value pairs are found to be inconsistent.

- *PHYSICAL/High Internal Access – HUMAN/Fragmented City; Revolutionary City*
- *PHYSICAL/Low Internal Access – HUMAN/Functional City; Hostile City*
- *MISSION/non-kinetic – HUMAN/Fragmented City; Revolutionary City; Hostile City*
- *MISSION/Low Kinetic – HUMAN/Functional City; Hostile City*
- *MISSION/High Kinetic – HUMAN/Functional City; Fragmented City; Revolutionary City*

The outcome of the cross-consistency assessment is a solution space consisting of 8 consistent solutions (Table 10). Further analysis of the solution space matrix indicates that it may be compressed into four main categories, shown in the gray column under "Operational Types".[11]

PHYSICAL	HUMAN	MISSION	OPERATIONAL TYPES
Low Int High Ext	Fragmented City	Low Kinetic	**Restoring the Fragmented City**
Low Int Low Ext	Fragmented City	Low Kinetic	
High Int High Ext	Functional City	Non-Kinetic	**Assisting the Functional City**
High Int Low Ext	Functional City	Non-Kinetic	
High Int High Ext	Hostile City	High Kinetic	**Fighting the Hostile City**
High Int Low Ext	Hostile City	High Kinetic	
Low Int High Ext	Revolutionary City	Low Kinetic	**Defending the Revolutionary City**
Low Int Low Ext	Revolutionary City	Low Kinetic	

Table 10: Solution space of aggregate analysis

Restoring the Fragmented City

Inadequate internal communication infrastructure, the collapse of monopoly of violence, and social and political fragmentation, combine to form a highly complex cityscape. Military intervention may conceivably have the restoration of order as its fundamental rationale, possibly supporting an expedient partner in re-establishing a monopoly of violence. Operating within an urban landscape among a population of non-combatants leaves little tolerance for collateral damage. The active use of force will be restricted, hence the mission will be low kinetic.

Assisting the Functional City

External influences – political, military or natural – may require a military force to assist an otherwise functional city. The purpose of assistance may include upholding external security, ensuring safety for its population, keeping up a basic level of public services, or advising a government. It is a precondition for establishing a mission that internal security functions are sustained by the city's own authorities; hence the intervening force has to conform to a non-kinetic mission set.

11 See Blanken et. al., 2017, p. 44-45.

Fighting the Hostile City

An intervening force entering a city firmly under the control of a coherent government without a partner will confront a hostile city. Hence, the intervening force must be prepared to fight the enemy through large scale use of force within the city itself. The ultimate goal of operations is to defeat organized enemy resistance and pacify the city populace.

Defending the Revolutionary City

In a revolutionary city, military intervention will have as its ultimate goal to defend and protect the city government from armed threats emanating from within the city itself. Rival actors operate out of ungoverned segments of the city where they draw on support from an alienated populace. Although a split city, the authorities maintain external legitimacy; hence, the city's authorities may seek formal partnership with an outside force in order to subdue rival actors through the use of low kinetic force.

This aggregate city-mission typology can be considered exhaustive in that it represents any plausible combination of the physical, human and mission related aspects of military operations in urban landscapes.

Conclusion

On the one hand, General Morphological Analysis relies on rigorous logical reasoning but, at the same time, its utility rests on the capacity to produce results that are useful for practitioners. Obviously, some tension might accumulate between the ideal of pure logic and the requirements of practical use. However, our standpoint on the issue is that any methodological tweak can be legitimate as long as it serves to produce practical, useable outcomes while not violating basic tenets of scientific inquiry.

The example case discussed in this article represents the problem of hyper-coherence in morphological models. While not necessarily a problem in itself, high degrees of coherence complicate the compression of the problem space into a significantly smaller solutions space that in its turn may be useful for further analysis and classification.

For the study of Human Built Operational Environments three conceptual bins, or core dimensions, were identified: *the physical, the human,* and *the mission*. Further unpacking of these resulted in six parameters: *external access, internal access, demographics, social expectations, governance,* and *mission.*

Instead of analyzing the total morphological field in one comprehensive process, the methodological tweak used in this case was to split the analysis into two tiers. First the core dimensions were analyzed separately, producing new abstract concepts that were brought into the next stage of aggregate analysis. Consequently, for the second tier analysis the morphological field consisted of new concepts developed in the first analytic round. These concepts are both more abstract and contain added information compared to the original morphological field. The second tier morphological model therefore is also more constrained than the original problem field, thus changing the model from being highly coherent to being highly constrained.

This methodological manoeuvre is what enables a final compression of the morphological field into an aggregate city-mission typology consisting of just four broad categories. *Restoring the fragmented city, assisting the functional city, fighting the hostile city, defending the revolutionary city*, thus, can be seen as representing the entire universe of urban operational environments that might confront an intervening force.

This method of breaking out and assessing morphological sub-fields, in order to compress and reduce otherwise hyper-coherent models, should find general applicability in morphological modelling. It shows that the morphological method has more flexibility than is sometimes assumed, and it may serve as an example of how an innovative use of the morphological toolbox can resolve seemingly intractable problems.

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