MANAGING SYSTEM COMPLEXITY

Through Integrated TD Design Tools

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Transdisciplinary modules are dedicated to Dr. Raymond T. Yeh and Mr. Bob Block, for their continued support of ATLAS, enthusiasm, dedication, and passion!

MODULE 1

Complex Problems and Transdisciplinarity

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> When you first start off trying to solve a problem, the first solutions you come up with are very complex, and most people stop there. But if you keep going, and live with the problem and peel more layers of the onion off, you can often times arrive at some very elegant and simple solutions.
>
> **Steve Jobs**

1.1 Complex Problems and Transdisciplinarity

A number of complex issues have begun to stand out as major concerns in the 21^{st} century. Complex problems such as the environment, climate change, immigration, hunger, water crises, world population, disease, and energy are some of the most serious issues affecting the world today. These issues that transcend disciplinary boundaries cannot be addressed by anyone discipline alone: Transdisciplinary approaches can offer solutions to these challenges by providing new skills and tools aimed at creativity, innovation, and collaborating across knowledge fields.

> "Convergence: facilitating transdisciplinary integration of life sciences, physical sciences, engineering, and beyond is an approach to problem solving that cuts across disciplinary boundaries. It integrates knowledge, tools, and ways of thinking from life and health sciences, physical, mathematical, and computational sciences, engineering disciplines, and beyond to form a comprehensive synthetic framework for tackling scientific and societal challenges that exist at the interfaces of multiple-fields. By merging these diverse areas of expertise in a network of partnerships, convergence stimulates innovation from basic science discovery to translational application. It provides fertile ground for new collaborations that engage stakeholders and partners not only from academia, but also from national laboratories, industry, clinical settings, and funding bodies."
>
> **National Research Council of the National Academies**

Transdisciplinarity deals with research problems and organizations that are defined from complex and heterogeneous domains, characterized by high levels of uncertainty, multiple perspectives, and multiple interlinked processes from local to global scales – good examples of such problems could be climate change, environmental issues, or public health challenges.[1,2] To give a specific example, the COVID-19 pandemic is a transdisciplinary societal challenge that requires collective intelligence and coordinated systemic thinking in the context of uncertainty–it is an example of complexity in action.[3]

> "Effective responses to the complexity, emergence, and uncertainty of coronavirus SARS-CoV-2 and the compound nature of health, economic and social impacts of COVID-19 require understanding and implementing the virtuous relations between disciplinary knowledge and professional know-how, several types of resources, coordinated multi-level governance, and individual and collective behaviors that should be combined in transdisciplinary contributions."[3]
>
> **Roderick J. Lawrence, 2020**

To handle complex problem challenges, researchers can develop collective information of knowledge by working together with diverse knowledge domain holders (actors) to co-create solutions – Transdisciplinary research enables the building of a range of actors and various stakeholders to create collective impact to solve unstructured problems.[4] Transdisciplinarity is about respecting non-research stakeholders, respecting their knowledge, engaging with them, and helping them do better through their research. It's this moral basis of transdisciplinarity that is believed that can be applied to just about all settings, because it's grounded in something so deep that it makes sense irrespective of context.[5]

Across academies, many scholars have been contributed to interdisciplinarity, transdisciplinarity, and integrated research concepts. Multidisciplinary activities bring together researchers from different disciplines working separately, each from their own discipline-specific viewpoint, to solve a common issue. In interdisciplinary activities, researchers from diverse disciplines work together on common problems by exchanging methods, tools, concepts, and processes among them to find integrated solutions. Both multidisciplinary and interdisciplinary activities cross discipline boundaries but their goal remains within the framework of disciplinary research.[6] Numerous articles have been published by Basarab Nicolescu on the scientific transdisciplinary research approaches.[7,8]

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[1] Apgar, J.M., Argumedo, A. & Allen, W. Building transdisciplinarity for managing complexity: lessons from indigenous practice. *International Journal of Interdisciplinary Social Sciences*, Vol. 4, No. 5, pp. 255-270, 2009.

[2] Lawrence, J. R. Deciphering interdisciplinary and transdisciplinary contributions. *Transdisciplinary Journal of Engineering & Science*, Vol. 1, pp. 111-116, 2010.

[3] Lawrence, J. R., (2020). Responding to COVID-19: What's the Problem? J Urban Health, The New York Academy of Medicine, https://doi.org/10.1007/s11524-020-00456-4.

[4] Vogel C. Transdisciplinary research for complex wicked challenges. Global Change Institute. https://www.wits.ac.za/gci/media/, Accessed January 2, 2020.

[5] Strunz, S. Is conceptual vagueness an asset? Arguments from the philosophy of science applied to the concept of resilience. *Ecological Economics*, 76: pp. 112–118, 2012. Online (DOI): 10.1016/j.ecolecon.2012.02.012.

[6] Ertas, A. Understanding of transdisciplinary and transdisciplinary process. *Transdisciplinary Journal of Engineering & Science*, 1(1), pp. 1-12, 2010.

[7] Nicolescu, B. Methodology of transdisciplinarity levels of reality, the logic of the included middle and complexity. *Transdisciplinary Journal of Engineering & Science*, vol 1, pp. 17-32, 2010.

[8] Nicolescu, B. *Manifesto of transdisciplinarity.* State University of New York Press, Albany, 2002.

Transdisciplinarity creates new key frameworks, such as general systems theory and sustainability. It also brings involving stakeholders in the research activities. The main actions are transcending, transforming, and transgressing.[9] The anticipated outcomes of transdisciplinary research and education are: emphasis on teamwork; searching for information from experts; developing and sharing of new concepts, methodologies, processes, and tools; all to create fresh, inspiring ideas that expand the boundaries of possibilities. The TD approach teaches people to seek collaboration outside the bounds of their professional experience to make new discoveries, explore different perspectives, express and exchange ideas, and gain new insights to solve difficult problems of contemporary societies of today's world.[10]

1.2 Defining Complexity

Complexity is difficult to understand due to the range of opposing proposed solutions and explanations for what creates complexity. Many researchers have suggested that complexity can be defined by size, entropy, information content, computational capacity, as well as others.[11] Many of the suggested definitions of complexity are created on identifying a quantifiable parameter for a system or problem; however, proposals to date have not provided an agreed-upon definition.[11]

There is a difference between complex and complicated systems/problems. Complicated and complex systems both may have various interactive components. Although complicated problems can be hard to solve, people with the right skills and expertise are addressable. However, there is no straight way to a solution for complex problems–they have too many unknowns and too many interrelated factors that are constantly changing in unpredictable environments.

The goal of this section is to provide a basic understanding of complexity rather than the theory of complexity studies or mathematical models. For example, our concern would be problems related to large-scale systems with numerous components and subsystems which interact in multiple and intricate ways with engineering, social, political, managerial, commercial, biological, and medical systems.[6]

Pierce stated that "Complexity is that sensation experienced in the human mind when, in observing or considering a system, frustration arises from lack of comprehension of what is being explored."[12] With this theory, complexity is dependent on the individual judge of a system, not the system itself.

Critical thinking scholar Richard Paul stated that "Governmental, economic, social, and environmental problems will become increasingly complex and interdependent... The forces to be understood and controlled will be corporate, national, trans-national, cultural, religious, economic, and environmental, all intricately intertwined."[13] However, many universities do not

[9] Klein, T, J. Integration – Part 1: The "what" Integration and Implementation Insights, 2016. https://i2insights.org/2016/08/30/what-is-integration/, accessed January 4, 2020.

[10] Ertas, A., Greenhalgh-Spencer, H., Gulbulak, U., Baturalp, T. B., Frias, K. Transdisciplinary collaborative research exploration for undergraduate engineering students. *International Journal of Engineering Education,* Vol. 33, No. 4, pp.1242-1256, 2017.

[11] Mitchell, M., Complexity: A Guided Tour, Oxford University Press, Oxford, 2011.

[12] Peirce, C. S., "How to Make Our Ideas Clear," *Popular Science,* pp. 286-302, 1878.

[13] R.W. Paul, The logic of creative and critical thinking. *American Behavioral Scientist*, 37 (1) (1993), pp. 21-39.

practice transdisciplinary learning to train the next generation of science, engineering, and business undergraduate and graduate students for a world of problems we currently cannot solve.

Simon specifies the four characteristics of complex systems as:[14]

1. Complex systems are frequently hierarchical.
2. The structure of complex systems emerges through evolutionary processes and that hieratic systems will evolve much more rapidly than non–hierarchic systems.
3. Hierarchically organized complex systems may be decomposed into sub-systems for analysis of their behavior.
4. Because of their hierarchical nature, complex systems can frequently be described, or represented, in terms of a relatively simple set of symbols.

Simon's third view of complex systems indicates a possibility that they can be decomposed for study and analysis. This characteristic, which provides the likelihood for dealing with complex systems, may not be easily realized. The interconnections and interactions of the parts of a complex system will not typically be obvious without considerable study. Finally, Simon notes that complex systems can often be represented by apparently simple arrangements of symbols that follow the hierarchical structure of the system. Herb Simon also stated that:[15]

> "Today, complexity is a word that is much in fashion. We have learned very well that many of the systems that we are trying to deal with in our contemporary science and engineering are very complex indeed. They are so complex that it is not obvious that the powerful tricks and procedures that served us for four centuries or more in the development of modern science and engineering will enable us to understand and deal with them. We are learning that we need a science of complex systems, and we are beginning to construct it."
>
> **Herb Simon**

In The Sciences of the Artificial Simon further states:[14]

> "The proper study of mankind is the science of design, not only as the professional component of a technical education but as a core discipline for every liberally educated person."
>
> **Herb Simon**

Warfield states his view of complex systems as:[16]

> "For better or worse, our society has accepted the idea of large and complex systems. If we are going to have them, it behooves us to learn how to manage them."
>
> **Warfield, 1994**

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[14] Simon, H.A., *The Science of Artificial* Third Edition, Cambridge, MIT Press, 1999.
[15] Simon, A. H., Keynote Speech, 2000 Integrated Design and Process Technology (IDPT) Conference, Dallas.

> "One of the primary motivations comes from recognizing that society today involves large sociotechnical systems whose performance is far from ideal. It is clear that many of these large systems have taken their present forms primarily through evolutionary change that did not involve any systematic overview design, but may have involved some systematic design of parts. Other systems are said to have been designed, but still fail in ways that produce disasters."
>
> **Warfield, 1994**

In Warfield's analysis, the human observer is involved with every obligation of complexity. Complexity has been described as a degree of unawareness. Objects are more or less complex depending on our unawareness or lack of information we have about it, our ability to make differences and insights about it, and our ability to conclude information from it. Warfield defined the complexity as:

> "That sensation experienced in the human mind when, engaged in observing or considering a system, frustration arises from luck of comprehension of what is being explored."
>
> **Warfield, 1996**

1.3 Characteristics of Complexity

The two different characteristics of complexity were described by Warfield as: *cognitive complexity* and *situational complexity*. Situational complexity is the complexity inherent to the system under question. Cognitive complexity describes the complexity associated with analysis by the observer. When the mind becomes oriented towards a complex situation, there is a possibility that cognitive complexity will start and then may escalate.[16]

Both situational and cognitive complexity must be considered when describing complexity. Every system with some number of components will have some level of situational complexity. There will be also some level of cognitive complexity due to the limited cognitive abilities of humans.[14] Human cognitive capabilities must always be thought as the human is involved with all aspects of complexity, according to Warfield.[17]

As shown in Figure 1.1, a concept of situational complexity framework can be illustrated in four categories based on the degree of certainty and level of agreement on the issue in question: simple, socially complicated, technically complicated, and complex.[18,19] The two main futures of the matrix shown in Figure 1.1 is the level of agreement and the certainty/comprehension about how to solve the problem. Certainty describes the predictability about how to solve the problem, and agreement describes the level of conflict about how to solve the problem.[20]

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[16]Warfield, J. N., *A Science of Generic Design: Managing Complexity Through Systems Design,* Ames: Iowa State University Press, 1994.

[17]Warfield, J.N., "Structural Thinking: Organizing Complexity Through Disciplined Activity," *Systems Research,* 13, 47-67, 1996.

[18]Zimmerman, B. (2001). Ralph Stacey's agreement & certainty matrix. Toronto, Canada: Schulich School of Business, York University.

[19]Stacey, R. D. (1996). Complexity and creativity in organizations. San Francisco, CA: BerrettKoehler

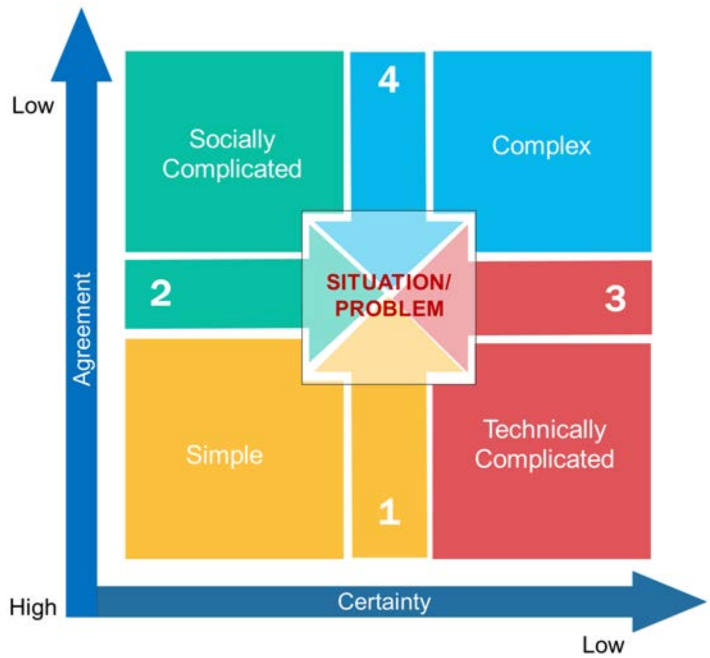

Figure 1.1: Agreement & certainty matrix (adapted from Zimmerman and Stacey).

Issues or problems are close to certainty when cause and effect linkages can be defined – a situation is simple, comprehendible and it can be solved with confidence. It is complicated when experts are required to formulate a complicated solution that will yield the anticipated results with certainty. An issue is complex when frustration arises from lack of comprehension of what is being explored. In the following, in Figure 1.1, the four quadrants are described separately and distinguished.[21]

The first quadrant (simple) on the matrix shown in Figure 1.1 which is close to certainty and close to an agreement, data are collected from the past and use that to predict the future. This is a good management practice for problem-solving and decision-making that fall in this area. The purpose is to repeat what works to increase efficiency and effectiveness.

The second quadrant (socially complicated) of Figure 1.1 shows that some issues have a high level of certainty about how outcomes are created but low levels of disagreement about which outcomes are desired. Neither plans nor shared missions are likely to work in this situation. Instead, politics become more important. Coalition building, negotiation, and compromise are used to create the best solutions.ome more important. Coalition building, negotiation, and compromise are used to create the best solutions.

Publishers.

[20]Scott Chazdon and Samantha Grant (2019). Situational Complexity and the Perception of Credible Evidence. *Journal of Human Sciences and Extension*, Volume 7, Number 2, pp. 36-60.

[21]The Stacey Matrix: http://adaptknowledge.com/wp-content/uploads/rapid intake/PI_CL/media/Stacey_Matrix.pdf, accessed June 27, 2020.

The third quadrant (technically complicated) shows that some issues have a high level of agreement but a low level of certainty as to the cause and effect linkages to create the expected results. In these situations, monitoring against a predetermined plan will not work. In this situation, a transdisciplinary approach could be used–a strong sense of shared mission or vision may replace a plan. In this region, the goal is to head towards an agreed-upon future state even though the specific paths cannot be determined.

The fourth quadrant (complex) shows that situations where there are very low levels of uncertainty and agreement. These situations often result in a breakdown or disorder. The traditional methods of planning, visioning, and negotiation are inadequate in these situations.

1.3.1 Subjective and Objective Situational Complexity

> "If I had an hour to solve a problem and my life depended on the solution, I would spend the first 55 minutes determining the proper question to ask... for once I know the proper question, I could solve the problem in less than five minutes."
>
> **Albert Einstein**

Situational complexity provides a framework to begin to explore evaluation questions.[22] Evaluation designs in complicated situations should take into consideration the system, stakeholders, and the situation of the problem under study. This will guide to more complex questions to investigate the linkages in the system.[20]

In certain situations, decision-makers select their decision based on multiple, diverse, and possibly incomplete information, thus, they face uncertainty regarding the situation at hand and the relationship between information (cues) and potential outcomes. This means that it is not possible for a decision-maker to be certain that an individual judgmental decision option is the best choice in a given situation. The concept of complexity is closely related to the nature of a judgmental decision – judgmental decision always includes some aspects of complexity.[23]

The situational complexity has two important dimensions: the perceptibility of information (cues) and the degree of uncertainty in a given situational environment.[24] We may discuss situational complexity in two groups as the subjective and objective types. The subjective perception of the complexity of the situation in question takes the observer into account, but varying importance is given to individual differences of the observer. On the other hand, objective complexity refers to the amount or degree of complexity physically present in a stimulus.

Another important concept within the field of human factors is situational awareness. The term awareness emphasizes the importance of memory which in part determines consciousness and awareness.[25] Our situational awareness will be limited if our attention is directed to inappropriate elements of the environment.[26] People's failure of selective attention such as talking on

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[22] Patton, M. Q. (2011). *Developmental evaluation: Applying complexity concepts to enhance innovation and use.* New York, NY: Guilford Press.

[23] Steigenberger, N., Lübcke, T., Fiala M. H., Riebschläger, A. (2017). *Decision Modes in Complex Task Environments.* CRC Press.

[24] Kahneman, D., Klein, G. (2009). Conditions for Intuitive Expertise: A Failure to Disagree. *American Psychologist*, Vol. 64, No. 6, pp. 515-526.

[25] Baddeley, A. (1999). *Essentials of Human Memory.* Hove, UK: Psychology Pres.

[26] Robert W Proctor, Trisha Van Zandt, (2018). *Human factors in Simple Complex systems.* CRC Press, Taylor & Francis Group, NW.

EXAMPLE 1.1

Analyze the situational complexity of the partially autonomous cars in which the driver's responsibilities are reduced.[26]

BACKGROUND

Autonomous vehicle technologies are developing at a faster pace in recent years. Think about a future where fully autonomous vehicles dominate the roads and how this will impact our lives. How will the way we live change when we expect vehicles to be able to drive themselves safely on the road and make a gesture at any time?

ANALYSIS

Automation of driving will only work during predictable situations such as driving on the highway. Driver must be prepared to *takeover* when the situation suddenly changes or automation fails. The takeover is a complex task – maintaining a level of awareness that permits the driver to re-engage attention when sudden action is required: situation awareness must be re-gained and the driver will return to the driving task. This process has to happen in a very short time but at the same time a safe and comfortable *takeover* should take place.

First, the *takeover* process is affected by the complexity of the surrounding traffic environment that can be defined as *objective situational complexity*. Secondly, other factors, such as weather conditions, road structure, etc. can also contribute to objective situational complexity. In particular, when taking over the driving task, the objective situational complexity can impact the quality of the *takeover* process.[28] For example, when a lane change is necessary during crowded traffic, takeover quality will reduce – because the choice of lane change is more complex than other driving activities.

Besides the objective situational complexity, the current state of each individual driver's (e.g., stress level, vigilance, the workload of non-driving related task) behavior can be different during the *takeover* situation. Since the individual perception of complexity is affected by the road traffic condition awareness, different driver's subjective perceptions of complexity in a certain traffic situation can be different. For example, because of the state of awareness, one driver may feel very comfortable with high traffic density and rate complexity of the situation as low, another driver might perceive the situation as more complex. This is called *subjective situational complexity*.[28]

a cell phone while driving may limit his/their situational awareness.[27] The following is a good example to explain situational awareness and complexity.[28]

[27] Endsley, M. R., Jones, D. G. (2012). *Designing for situation awareness: An approach to human-centered design (2nd ed.)*. London: Taylor & Francis.

[28] Scharfe, M., Zeeb, K., Nele Russwinkel, N. (2020). The Impact of Situational Complexity and Familiar-

EXAMPLE 1.2

Analyze the situational complexity of the COVID-19 pandemic.

BACKGROUND

Starting in 2019, the world is engaged in a complex task environment – that is, fear and anxiety about a new infectious Coronavirus Disease (COVID-19). The COVID-19 pandemic is an example of complexity in action – creates complex humanitarian, economic, social, and health crises.

The world's scientists and global health professionals getting together to accelerate the innovative research to develop vaccines to control the spread of the COVID-19 pandemic and help care for those affected.

ANALYSIS

The spread of the disease is influenced by people's willingness to adopt preventative public health behaviors – such as social distancing and wearing masks. But, social distancing might make people feel isolated and can increase stress and anxiety. However, these actions are necessary to reduce the spread of COVID-19.

Human behavior is affected by people's knowledge and perceptions – depending on the individual judgmental decision, one person may think COVID-19 is basically like another flu or it only affects old people, thus he/she doesn't adopt preventative public health behaviors – their risk perception of COVID-19 is low. On the other hand, another person may perceive the risk of getting an infection with COVID-19 is relatively high: they adopt preventative public health behaviors and take extra precautions.

As we can see from this subjective situational complexity example, people's level to understand the risk perception on COVID-19 is different. This could be because of the individual judgmental decision, perception, or awareness of the situation.

Based on the information at this time, people with the following underlying medical conditions might be at an increased risk for severe illness from COVID-19: people 60 plus years old or with health conditions like lung or heart disease, diabetes, or conditions that affect their immune system – if we assume that those are facts then we call this objective situational complexity.

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ity on Takeover Quality in Uncritical Highly Automated Driving Scenarios. *Information*, Vol. 11, Issue 2, 10.3390/info11020115.

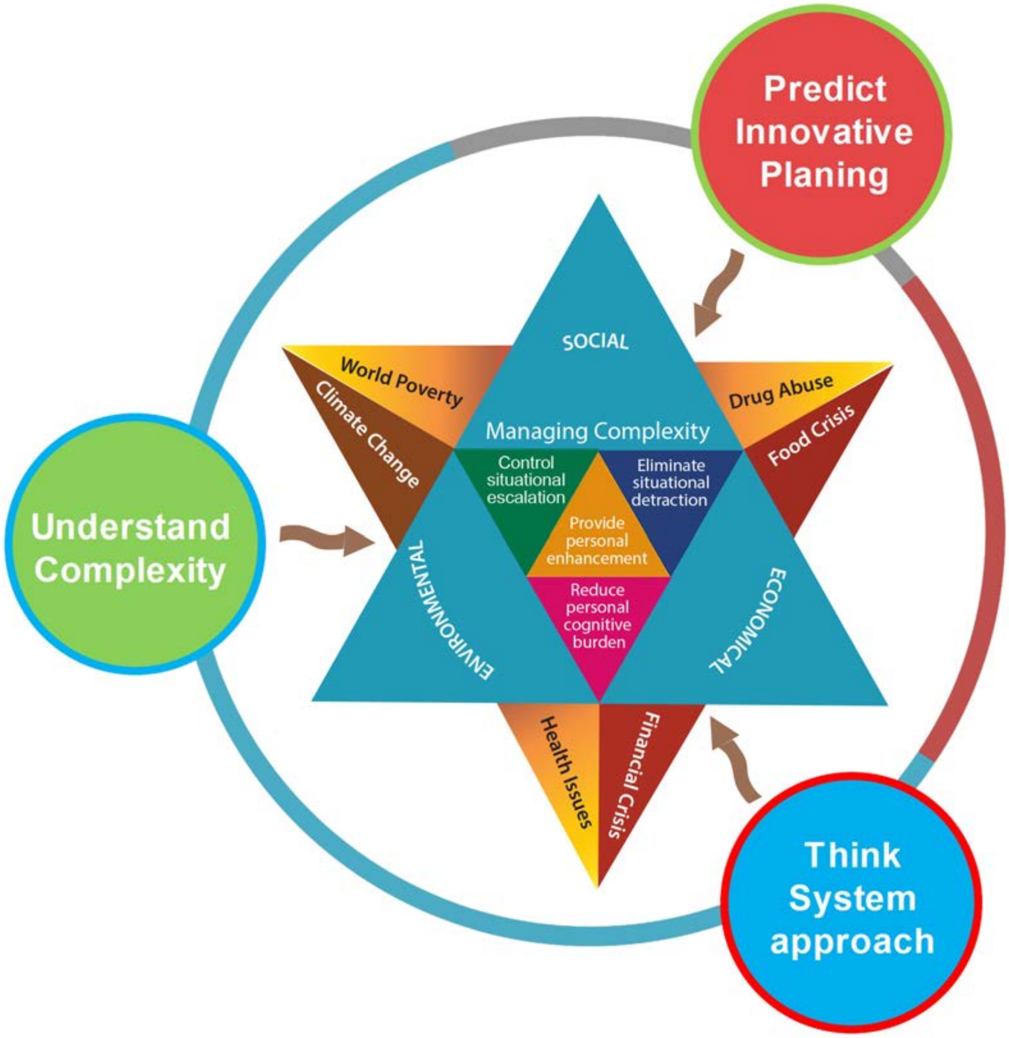

Figure 1.2: Managing Complexity.

1.4 Managing Complexity

It is important to understand the complexity of an issue and how it affects the understanding and projection of the solution. It is also crucial to managing complexity so that it does not overwhelm the design effort and prevent the development of effective solutions. In this regard, understanding of the complexity and the principal aspects of the path to the management of complexity shown in Figure 1.2 will be very briefly covered in this section.[29] Figure 1.2 shows

[29]Ertas, A., *Transdisciplinary Engineering Design Process.* John Wiley & Sons, Inc., NJ, USA, 2018.

Figure 1.3: Managing Complexity.

some of the complex issues that impact directly on individuals, families, and communities and have effects on the lives of people – as shown in this figure, complex issues can be environmental, social, or economic.

TD program planning is an innovative process requiring broad comprehension along with a goal-oriented transdisciplinary approach. It is a challenging TD activity − Since more resources are involved, more innovation, creativity, and care must go into the program planning. The plan must identify the specific activities required to predict feasible solutions.

Systems thinking is the process of understanding how the elements of a system interacting with one another and the ability or skill to perform problem-solving associated with them. For example, in nature, ecosystems are a complex set of interacting system-of-systems (SoS) – various elements such as air, water, movement, plants, animals, and as whole earth work together to survive or perish. This subject will be covered with applications in the proceeding sections.

1.4.1 Required Conditions for Managing Complexity

Although it may not be possible to identify required conditions for managing complexity, as shown in Figure 1.3, the following four necessary and sufficient conditions will be discussed in this section.[16]

1. *Controlling Situational Escalation*: Situational escalation may occur because of the following factors: (a) when analyzing complex problem-solving in teams, varying perceptions

among the team members, (b) difficulty in managing group of professionals working together to solve a complex problem, (c) the existence of organizational or cultural constraints that hold back the valuable contribution to problem-solving, (d) difficulty of communication issues and implementation of problem solutions with customers, (e) change in the problem situation and decision making with time, and (f) lack of participants to fill new, needed responsibilities. Overcoming these issues may be possible if the team's sense of coherence exists. It is important to note that resolutions to one factor don't necessarily resolution of others, and may even escalate them.

2. *Reduce Personal Cognitive Burden*: Let's consider a group of researchers (problem-solving team) working together to solve a complex issue. If one of the group members is in the position of trying to be part of the research activity to provide opinions and decisions for which the group member is not cognitively prepared then escalation of complexity will start – this situation is one of the evidence of mismanagement of complexity and creates a personal cognitive burden on the individual. Instructional design can be used to reduce the cognitive burden on learners.[30]
3. *Eliminating Situational Detraction*: Besides the factors affecting complex issues, there are many other situational factors that often exist which detract from problem-solving activity. Some of such factors are: (a) intrinsic (bounded rationality, imbalanced perception of problem factors, false saliency); (b) Cultural (narrow-mindedness, myopic vision); (c) Extrinsic (consuming egotism, arrogant abuse of power, knowledge disavowal).
4. *Providing Personal Enhancement*: The last of the necessary conditions for managing complexity is making available suitable conditions or entities or other means to enhance the capability of the individual to be effective in a problem-solving situation. For example, creating an effective group process, display of structured and unstructured information organized dialog, etc.

It is important to note that these four necessary conditions are not independent of one another.

1.4.2 Interactive Collective Intelligence Management

The concept of Interactive Management (IM) was developed at the University of Virginia in 1980. Since then, the practice of IM has spread to many places, and many applications have been implemented. IM is a system of management invented explicitly to apply to the management of complexity. IM was developed especially to apply management of complexity to cope with issues whose scope is beyond that of the normal type of problem that organizations can readily solve.[31]

IM has been renamed as Interactive Collective Intelligence Management (ICIM) to be the building block of the Transdisciplinary Design Process.[29]

As shown in Figure1.4, ICIM has three phases.[31]

[30] Paas, Fred; Sweller, John (2011). An Evolutionary Upgrade of Cognitive Load Theory: Using the Human Motor System and Collaboration to Support the Learning of Complex Cognitive Tasks. *Educational Psychology Review.* 24 (1): 27–45. doi:10.1007/s10648-011-9179-2.

[31] Warfield J. N., and Cardenas, A. R., A Handbook of Interactive Management, Iowa State University Press/AMES, 1994.

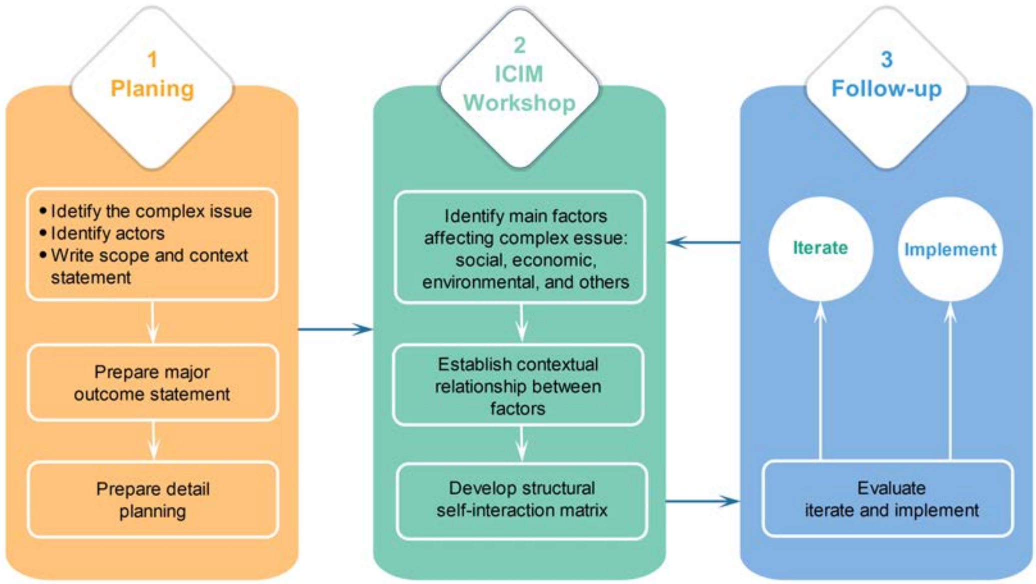

Figure 1.4: Three phases of Interactive Collective Intelligence Management (ICIM).

Planning Phase: The aim of the planning phase is to make all the necessary preparations to accomplish the ICIM workshop. In this phase, the complex issues understudy will be clearly identified and knowledgeable experts in the field will be carefully selected and invited to participate. Once the scope of the issue is described, a context statement is written to focus the ICIM workshop – working environment of the ICIM workshop will be described.

Specific, measurable, and realistic major outcome statements will be planned and defined. Detail planning will be prepared on: methodologies to be used; triggering questions to be asked; generic questions to be used; types of field experts needed; the role of the participants during the ICIM workshop; schedule, place, and the budget of the ICIM workshop, etc. participants during the ICIM workshop; schedule, place and the budget of the ICIM workshop, etc.

ICIM Workshop Phase: The ICIM Workshop phase implements the plan that is developed in the planning phase. The workshop phase involves bringing a selective group of people together from expert domains who have knowledge about the issue under study to create extensive communication among the group members to discover the main factors affecting the complexity of an issue.

At the beginning of the workshop, the facilitator will make available flip charts to display the context statement of the workshop and a brief outline of the Nominal Group Technique (NGT). NGT is an efficient method for generating new ideas in groups, clarifying the generated ideas, editing and grouping the ideas, and developing an initial ranking of the set of ideas.[32]

The facilitator writes the problem or issue on a whiteboard to establish the factors affecting

[32]Delbecq A. L. and VandeVen A. H, (1971). A Group Process Model for Problem Identification and Program Planning. *Journal Of Applied Behavioral Science* 7, 466 -91, 1971.

the complex issue. Using NGT, participants write down their ideas on the factors affecting complex issues in short sentences, one idea per sticky note until all their ideas are exhausted. Then ideas on factors proposed can be grouped together for open discussion by the participants. The facilitator asks each participant to priorities the factors that have been discussed and tallies their votes.

Then, the working group continues to deliberate for establishing contextual relationships among the factors to develop structural self – interaction matrix required fundamental knowledge to decompose the complex issue into understandable and meaningful pieces.

Follow-up Phase: The follow-up phase includes iteration of the problem solution and its implementation. The outcomes obtained through this ICIM workshop process include:[31]

- **Learning.** Students who participated in the ICIM workshop process are exposed to a real sharing of ideas and information, and therefore are actively learning about the design research project at hand.
- **Commitment.** The final design project concept is created through the collaboration of students and instructors. Through this kind of approach, true commitment can be achieved.
- **Documentation.** During the ICIM workshop process, information, and decisions generated by research team members were documented and organized – provide the basis for broader dissemination of the outcomes.

1.4.3 Measuring Situational Complexity

The Situation Complexity Index (SCI) has been proposed as a combined single metric to compare complexity among a group of problematic situations. Situation Complexity Index is the product of the Miller Index, the Spreadthink Index, and the Demorgan Index. It is defined as:[33]

$$SCI = (\frac{N}{7})(\frac{V}{5})(\frac{K}{10}) \tag{1.1}$$

If SCI is over 100, then the situation is considered to be complex. In Equation 1.1, $(N/7)$ is identified as the *Miller Index*. George A. Miller discovered the famous "magical number seven, plus or minus two". If the number N happens to be 7, the value of the Miller Index will be 1.0 which can be taken as a reference point. For values less than this magical number of seven, it is assumed that human being is capable of functioning well. In Equation 1.1, $(V/5)$ is identified as the *Spreadthink Index*. The Spreadthink Index is a measure of the disagreement among the participant group on the relative importance of the N problems they have generated. In the above equation, V is chosen to be the “selected subset”. The NGT voting system allows each voter to choose confidentially the 5 most important problems as he/she sees significant. If V=5, the spreadthink index will be the value of 1 which means that complete consensus. For values greater than 1, Spread Index indicates that the consensus is not achieved – it means that complexity is present. In Equation 1.1, the *De Morgan Index* is found from the simple formula $K/10$. When the De Morgan Index is 1, it indicates that the relationships among problem factors of an issue are acceptable and manageable with routine practices. For values exceeding 1, the De Morgan Index indicates that complexity is present.

[33] Warfield, N. J. Understanding Design Science, and its Implementation. First World Conference on Integrated Design & Process Technology, The University of Texas at Austin Texas, 1996.

EXAMPLE 1.3

Analyze the situational complexity of the refugee resettlement.

BACKGROUND

People are on the move for many reasons such as war and civil war, human rights, violation, economic, social, climate, environmental, political, and individual reasons that create these changing aspects. In such complex situations, the need to flee (forcibly displaced) versus the choice to leave (migration) can be difficult to determine. The issue of refugee resettlement is complex and includes many factors to consider.[34]

ANALYSIS

Transdisciplinary Collective Intelligence methodology implementation against this problem consisted of a group of 25 undergraduate students in senior design class, all pursuing Mechanical Engineering degree at Texas Tech University, two PhD students, one faculty member in design, four research engineers from different companies. This group recognized significant difficulties and challenges in carrying out successful refugee resettlement and sought to identify the main factors affecting the problem and how they were interrelated, with the goal of improving the rate of success for these displaced individuals.

The working group developed a set of factors affecting the complex issues of refugee settlement and they showed that how the selected factors are related to each other. One of the Ph.D. students, who are familiar with the ICIM facilitated the workshop. The working group developed transdisciplinary collective intelligence using the Interactive Collective Intelligence Management workshop to investigate the issue. The Nominal Group Technique was used to develop and clarify a list of factors affecting the complex issue. 124 problems identified and clarified. 20 problem categories are defined. 9 major problem areas were selected. Relationships among the major problem areas were 16. Table 1.1 shows values of the Miller Index, the Spreadthink Index, and De Morgan Index from the ICIM workshop carried out in the 2020 Spring semester at the Mechanical Engineering Department. As shown in Table 1.1, since the value of SCI is larger than 100, it was concluded that the refugee resettlement issue is complex.

Table 1.1: Values of metrics of complexity.

Problems Identified **(N)**	Problems Selected **(V)**	Problems Structured	Number of Relationships **(K)**	Complexity Index **(SCI)**
124	20	9	16	113.34

$$SCI = (\frac{N}{7})(\frac{V}{5})(\frac{K}{10}) = (\frac{124}{7})(\frac{20}{5})(\frac{16}{10}) = 113.34$$

[34] Moran, D., Gulbulak, U., Ertas, A., and student group, (2020). Complexity of Global Refugee Crisis:Needs for Global TD Collaboration. *Transdisciplinary Journal of Engineering & Science*, Vol. 11, pp. 115-131.

1.5 Complex Societal Problems and Transdisciplinarity

Societal problems are real and people face them in their daily life. They are highly complex because of their dynamic character and impact on society.[35] Societal challenges are highly transdisciplinary, with social, cultural, economical, political, environmental, and emotional issues interconnected with technology.[29] They cannot be simply solved by experiment, and the implementation of an alteration to a problem changes the social system in a complex way.[36] Crucial societal problems, such as climate changes, world poverty, health care, food crisis, and drug abuse, bring uncertain constraints with a high level of complexity for the people in dealing with them to solve. Cronin stated:[37]

> "There is a need for transdisciplinary research (TR) when knowledge about a societally relevant problem field is uncertain, when the concrete nature of problems is disputed, and when there is a great deal at stake for those concerned by problems and involved in dealing with them. TR deals with problem fields in such a say that it can: a) grasp the complexity of problems, b) take into account the diversity of life world and scientific perceptions of problems, c) link abstract and case specific knowledge and d) constitute knowledge and practices that promote what is conceived to be the common good."

Figure 1.5 shows the societal problem-solving process (SPSP). SPSP has three elements: Problem, Methodology, and Transdisciplinary Team. As shown in Figure 1.5, these three elements have connecting relationships – they are the major components of the exploration required to develop useful solutions.[38]

The generic tools for problem-solving may include communication tools, science tools, and technical tools. Problem solvers will select from those appropriate tools for societal problem-solving process structuring. It should be noticed that stakeholders involved with problem solutions may not be necessarily scientists. Content specialists are research participants who have acquired specialized knowledge that is relevant to an issue under study. Process modelers document a detailed description of the process that will be used for the problem solving and make sure that process rules and policies are followed. The research team evaluates each solution to select the one that shows the most potential to solve the problem, and then effectively implements the chosen solution. Management of the problem-solving process on social issues is crucial.

The societal problem-solving process requires a transdisciplinary team approach for the following reason:

- Values and subjective judgments play an important role in societal problems-solving. – requires consensus decision-making through deliberating among the transdisciplinary team.
- The number of elements and their relations affecting the solution of the societal problem is large – tackling large-scale problems is not an easy task and requires a transdisciplinary team effort.

[35]Dorien J. DeTombe, (2001). Compra, a Method for Handling Complex Societal Problems. *European Journal of Operational Research*, 128, 266–281, 2001.

[36]Warfield, N. J., *Societal Systems,* Intersystems Publications, USA, 1989.

[37]Cronin, K. Transdisciplinary research and sustainability. Environmental Science and Research (ESR), ltd., 2008.

[38]Warfield, N. J., Hill, J. D., (1973). An assault on complexity. A battelle Monograph, No:3, April 1973.

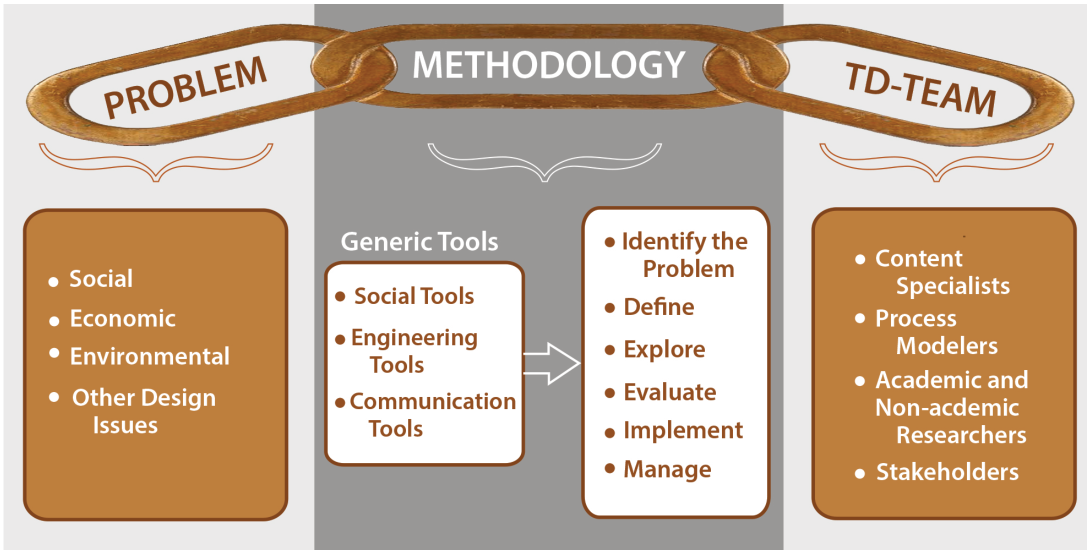

Figure 1.5: Societal problems solving process.

The large problems of growing society require collections of specialists using their specific knowledge in a common effort to the large scale of societal problems solution – there is a need to encourage and promote transdisciplinary research.

1.6 Understanding Hierarchical Relationships and Complexity

The connection between hierarchies and complexity has been studied by Simon extensively.[14] He considers four aspects of complexity take the form of hierarchy. They are:

1. “ The frequency with which complexity takes the form of hierarchy”
2. “The relation between the structure of complex systems and the time required for it to emerge through evolutionary process”
3. “The dynamic properties of hierarchically organized systems and... how they can be decomposed into subsystems in order to analyze the behavior”
4. “The relations between complex systems and their descriptions.”

Walter Wallace emphasizes two distinct kinds of things to deal with when studying complexity. These are *elements* and *relations*.[39] Relationship states that how two or more elements are related – defines the connection between two elements.

[39]Wallace, W. L., (1969). *Sociological Theory.* Aldine Publishing Company, Chicago.

In working with complex problems and in working with systems, the study of hierarchies is essential. The three principal concepts of a hierarchy are:[40]

1. elements (factors) that are to be arranged in a hierarchy,
2. content and directions of any relations among any pair of these elements, and
3. subordinate relations.

The following is a good example to explain factors that are to be arranged in a hierarchy when studying sustainable self-sufficient ecovillage.

EXAMPLE 1.4

Analyze the factors affecting that are to be arranged in a hierarchy when studying performance of sustainable self-sufficient ecovillage.

BACKGROUND

Performance goals for the ecovillage may include: reduction of energy (using green buildings, wind and solar energy), natural resource management, reduction of water use, waste treatment, recycling, and production of fruits and vegetables guided by intertwined with educational, economical, environmental, sustainable and social goals.[41]

ANALYSIS

Using the Nominal Group Technique, a group of ICIM workshop participants defined a set of factors affecting ecovillage performance and developed the hierarchy shown in Figure 1.6

As shown in Figure 1.6, the bottom three levels of the pyramid are called 'basic needs' because, in order to have healthy ecovillage, those basic needs must be met. If they do not exist, ecovillage becomes questionable. Thus, unity and strength through diversity; requirements of environmental issues such as nontoxic environment, recycling, air, water, and soil protection; renewable energy such as solar, wind, hydro energies; green buildings such as the efficiency of buildings with respects to conservative water, energy, and materials use are basic needs and requirements of any ecovillage designed to be fully self-sufficient.

Once the basic needs of ecovillage have been met, our focus shifts to the highest level-IV of hierarchy – economic dimension and social issues. Top level-IV of the hierarchy of the pyramid is called 'sustainability needs'. To build a true ecovillage community for the positive transformation we should go beyond the basic needs.

[40] Warfiled, J. N., (1973). *An Assault on Complexity.* Battelle Memorial Institute.

EXAMPLE 1.4 (continued)

ANALYSIS

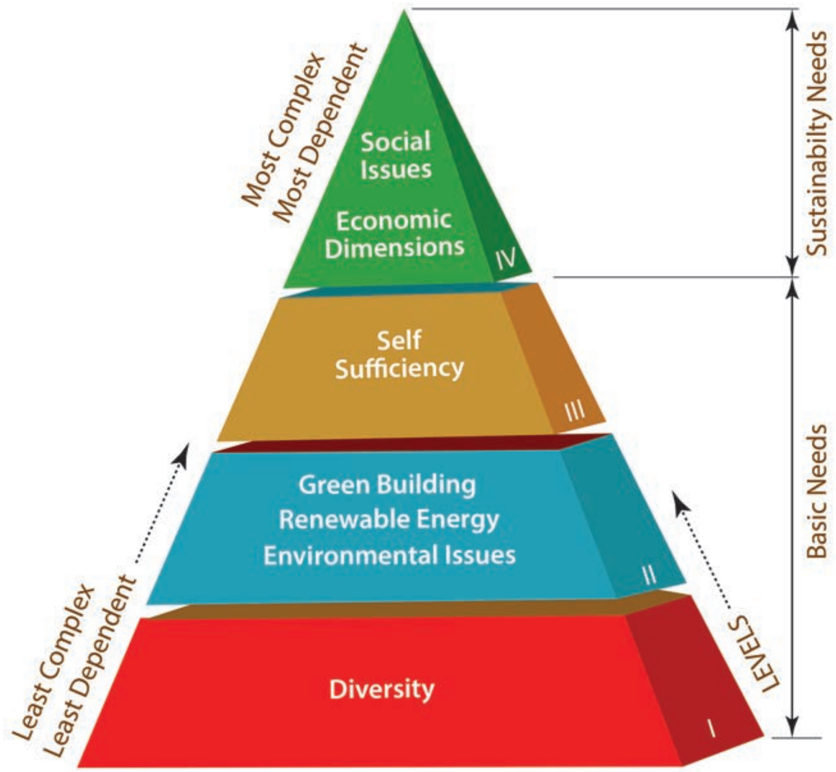

Figure 1.6: Hierarchy of factors affecting ecovillage performance.

Ecovillage goal is to build economic practices and social systems – provide sustainable alternatives to the mainstream economy and develop a fair, effective, and accountable social community. Of course, the goal is to develop an ideal sustainable ecovillage. Unfortunately, development progress is often interrupted by a failure to meet lower-level needs because of the highly complex interrelated nature of the problem. Also, for example, the economic dimension is extremely dependent on all the factors in the lower hierarchy which creates high complexity for sustainable economic accomplishment. The same argument can be said for social issues. The factor of diversity is the independent key driver (all the other factors affected by this factor) for the ecovillage performance – as diversity has an impact on many factors with least complexity, ecovillage participants have to pay maximum attention to establish a diverse but integrated community for a peaceful, healthy, and sustainable living so that related issues will not be out of control.

[41] Ertas, A., Rohman, J., Chillakanti, P., and Batuhan B. T., (2015). Transdisciplinary Collaboration as a Vehicle for Collective Intelligence: A Case Study of Engineering Design Education. *International Journal of Engineering Education*, Vol. 31, No. 6(A), pp. 1526–1536.

1.6.1 Forming Relationships Matrix

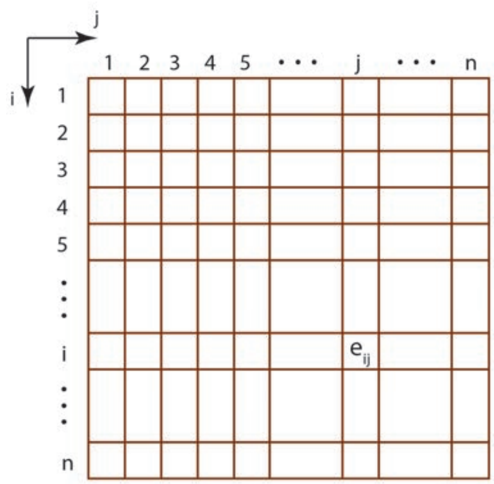

Figure 1.7: System elements relationships (dependency) matrix.

Three main tasks to form the relationships matrix are: 1) identify the relevant set of elements affecting the issue or problem, 2) determine the relationship among the elements, 3) translating the relationships in the form of *system matrix.*

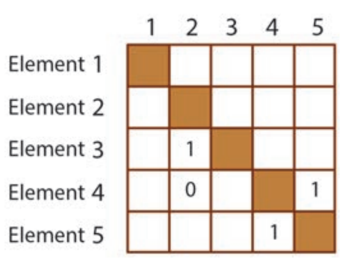

Figure 1.8: Relationships matrix.

System elements relationships matrix shown in Figure 1.7 is a square $n \times n$ matrix.The entries e_{ij} in the i^{th} row and j^{th} column indicates the relationships between elements i and j. If element i doesn't have relationship with element j, the entry e_{ij} will be zero. If element i is reaching (affecting) element j, enter a "1" in position e_{ij}. Since element j is not affecting element i, enter "0" in position e_{ji}. If elements i and j both reaching each other then the entry for both e_{ij} and e_{ji} will be "1".

For example, in Figure 1.8, element 3 is reaching element 2 but there are no relationships between elements 4 and 2. As seen from this figure, elements 4 and 5 are reaching each other, in other words, element 4 is affecting element 5, and element 5 is affecting element 4 – this is called *cycle*. The following example will show how to develop a relationship matrix.

EXAMPLE 1.5

Develop relationships matrix to reduce the cholesterol level considering below identified factors:

1. **to reduce cholesterol**
2. **to diet,**
3. **to exercise every day, and**
4. **to run every day.**

BACKGROUND

The American Heart Association (AHA) states that the above factors affect cholesterol levels by changing triglycerides, LDL, and HDL cholesterol levels. These changes may cause the risk for heart disease and stroke (adapted from reference 40).

ANALYSIS

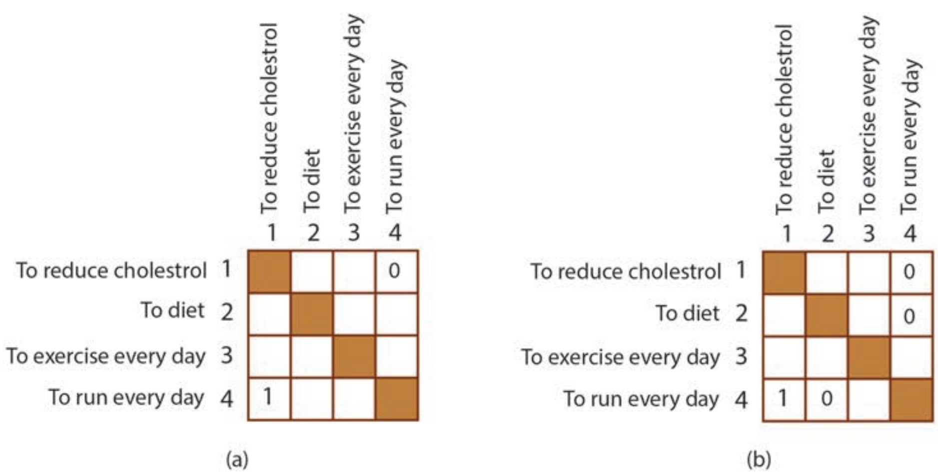

Figure 1.9: Partially completed matrix.

As shown in Figure 1.9(a), block all the entries on the matrix diagonal. In other words, set them to zero.

Referring to Figure 1.9(a), to run every day affects the reduce of cholesterol (set $e_{41} = 1$) but to reduce cholesterol doesn't affect to run every day (set $e_{14} = 0$). As shown in Figure 1.9(b), to run every day doesn't affect dieting (thus set $e_{42} = 0$) and to diet doesn't have relationships with running everyday (thus set $e_{24} = 0$).

EXAMPLE 1.5 (continued)

ANALYSIS

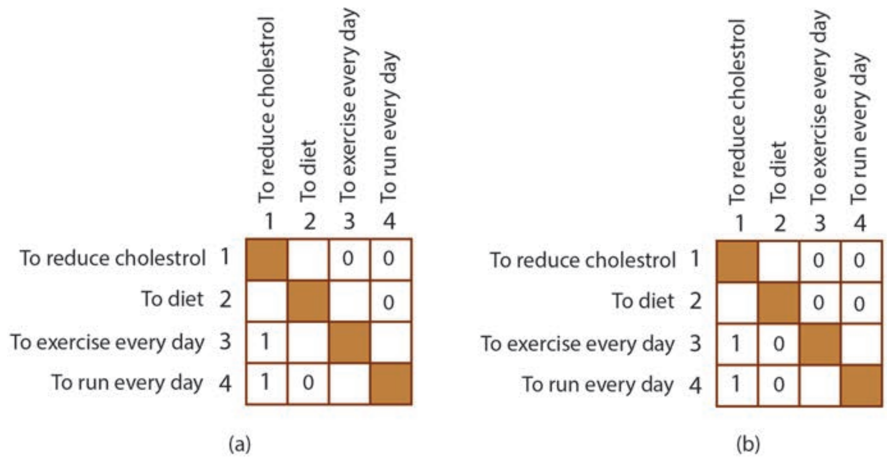

Figure 1.10: Partially completed matrix.

Figure 1.10(a): To exercise every day will reduce cholesterol level (thus set $e_{31} = 1$) however, to reduce cholesterol doesn't support the relationships with exercise everyday (thus set $e_{13} = 0$). Figure 1.10(b): to exercise doesn't contribute to diet (thus set $e_{32} = 0$). Dieting doesn't affect exercising (thus set $e_{23} = 0$).

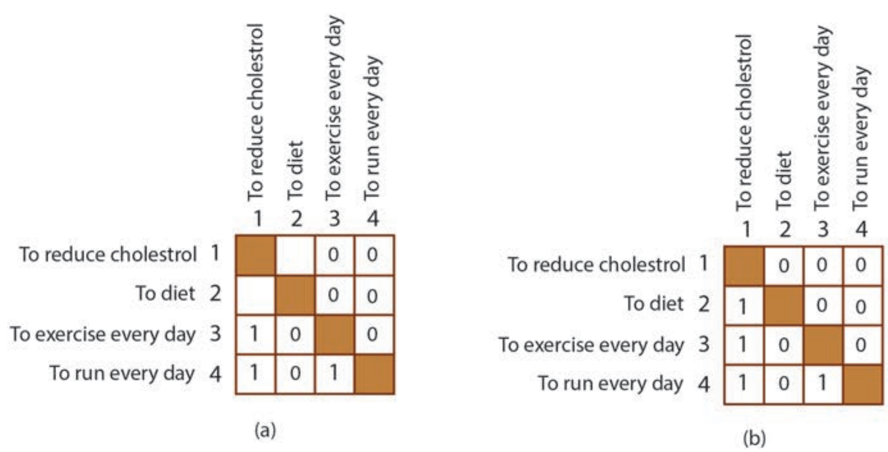

Figure 1.11: Figure 11(b) is completed matrix.

Figure 1.11(a): To run every day supports exercising (thus set $e_{43} = 1$), however, to exercise every day doesn't support the relationships with running everyday (thus set $e_{34} = 0$). Figure 1.11(b): to diet reduces cholesterol (thus set $e_{21} = 1$). To reduce cholesterol will not affect dieting (thus set $e_{12} = 0$).

EXAMPLE 1.5 (continued)

ANALYSIS

Finally, using the final relationship matrix shown in Figure 1.11(b), develop a digraph as shown in Figure 1.12. The matrix is shown in Figure 1.11(b) has four elements: therefore hierarchy will show these elements by numbers. Wherever there is a number 1 in the matrix, there will be a connection (relationship) between the associated elements. For example, since matrix shown in Figure 1.11(b) has $e_{3,1}$, the direction of the link will go from 3 to 1 – using the same approach complete digraph can be developed as shown in Figure 1.12.

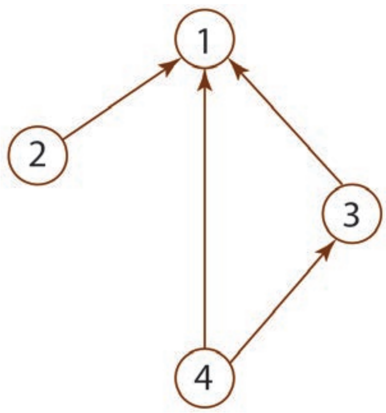

Figure 1.12: Digraph associated with Fig 1.11(b).

1.6.2 Graphical Representations

As Simon defined "complex systems," have a large number of elements that have many interactions.[14] Hierarchical systems consist of element relationships to each other and can be represented by a directed graph. A directed graph (digraph) shown in Figure 1.12, has a set of elements (in this case 4 elements) that are connected together, where all the links are directed from one node (element) to another.

When drawing a digraph, the links (edges) are drawn as arrows indicating the direction, as shown in Figure 1.13. The arrow shows the direction of the linkage. For example, in Figure 1.13(a), element 2 is reaching (affecting) element 3 and element 4 is reaching to element 2. Elements 1 and 4 are reaching each other and creating a loop (cycle). The directed graph is shown in Figure 1.13(a) provides another important piece of information – since element 4 is related to element 2 and element 2 is related to element 3, then element 4 is related to element 3 through the intermediate element 2 (this is called *transitivity rule*). This is shown in Figure 1.13(b).

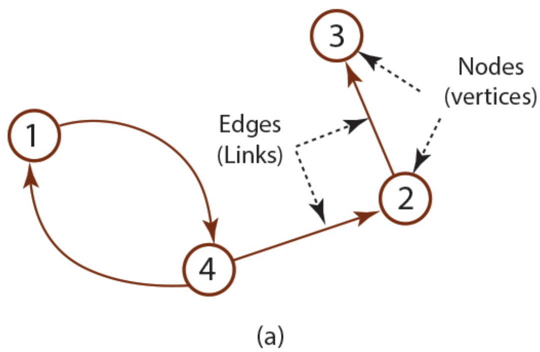

Figure 1.13: Directed graph (digraph).

1.6.3 Cycles in Digraph

A cycle in a digraph is a non-empty directed path in which the only repeated nodes are the first and last nodes – the first node of the path corresponds to the last. If a graph has a cycle it is a cyclic graph. A graph without cycles is called an acyclic graph.

As shown in Figure 1.14, node 2 and 3 makes a two-element cycle and nodes 1, 2, 4 make a three-element cycle, which means that these two and three elements are coupled, respectively. Figure 1.14 also shows the simplest possible cycle – a cycled called *self-loop*. In other words, element 1 is related to itself in some way.

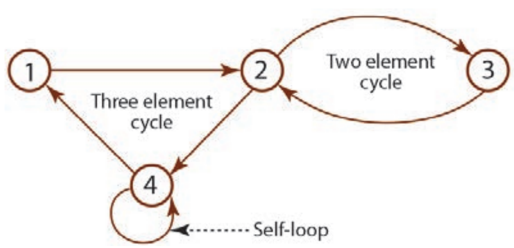

Figure 1.14: Cyclic graph.

EXAMPLE 1.6

Explaining cyclic situations with chicken or egg examples.

BACKGROUND

Chicken or egg situation is a good example to explain cyclic graph – it is impossible to make a decision which of two things existed first: chicken or egg?

EXAMPLES

For example, in order to get a job you need to have experience, but oftentimes without work experience you cannot get a job. This is a chicken and egg situation – it is difficult to know if the cause of the problem is not to have work experience or not have of job.

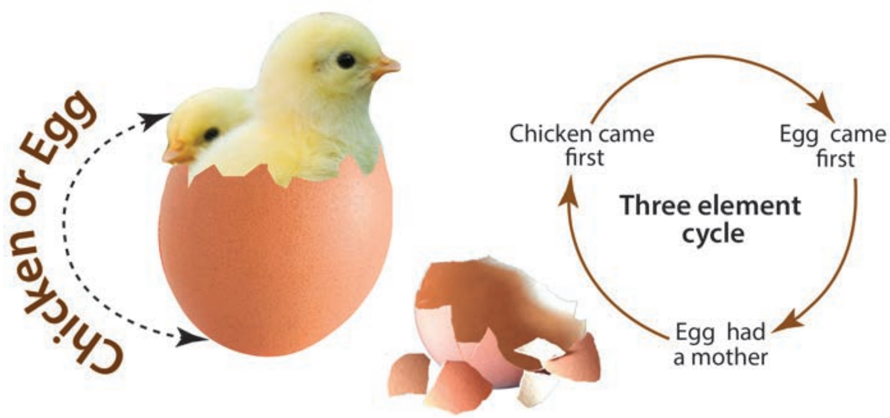

Figure 1.15: Chicken or egg situation.

More complex cycle involve of three elements is shown in Figure 1.15 – chicken or egg cycle. If the chicken came first, then it eventually had to hatch from an egg. If the egg came first, then it had to have a mother to create the egg. If the egg had to have a mother, then the mother should be the chicken – it is impossible to identify the starting point of a circular (cyclic) cause. This kind of situation may create uncertainty in design and makes the design effort complex.

1.6.4 Cyclomatic Complexity

Cyclomatic complexity is used to measure the complexity of a software program. Based on a control flow representation of a program, it was developed by Thomas J. McCabe in 1976. Control flow represents a program as a graph that contains nodes and edges – similar to digraph

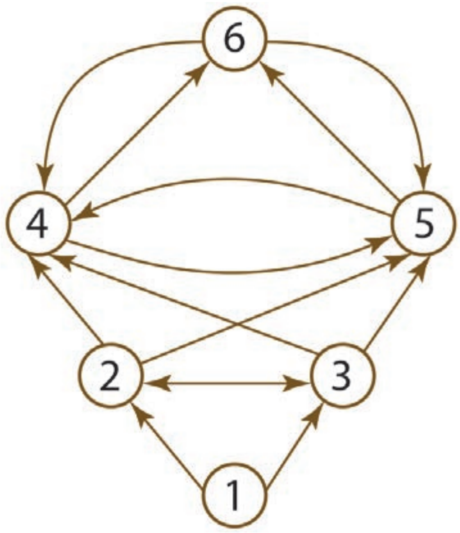

Figure 1.16: Digraph with six nodes.

as shown in Figure 1.16. In this figure, nodes represent processing tasks while edges represent control flow between the nodes. Mathematically, the Cyclomatic complexity, M is calculated by

$$M = E - N + 2P \tag{1.2}$$

where
E = the number of edges of the graph
N = the number of nodes of the graph
P = the number of connected components

The number of edges shown in Figure 1.16 is 13, the number of nodes is 6, and the number of connected components, P is equal to 1. Then, the Cyclomatic complexity M of the digraph given in Figure 1.16 is

$$M = 13 - 6 + 2 \times 1 = 9$$

We may conclude that the system represented by Figure 1.16 is considered very close to the limit to be complex suggested by McCabe.

The complexity of an issue will be difficult to understand when the Cyclomatic complexity number is high. The threshold limit value of Cyclomatic complexity was suggested by McCabe – "the particular upper bound that has been used for Cyclomatic complexity is 10 which seems like a reasonable, but not magical, upper limit."[42]

Profound measurement of complexity can help to improve our understanding and ability to work with complex systems. With the help of Cyclomatic complexity measure, it will be possible

[42]McCabe, T. J., "Describing Cyclomatic Complexity," *IEEE Transactions on Software Engineering,* Vol. 2, No. 4, p. 308, 1976.

to track complexity changes over several product generations. It is also possible to benchmark one company's product or processes complexity with respect to its competitors.

Although a general complexity measure has remained abstract, the following factors can be considered for complexity measures:

- The number of decomposed elements (components, tasks, or teams)
- The number of interactions to be managed across the elements
- The uncertainty of the elements and their interfaces
- The patterns of the interactions across the elements (density, scatter, clustering, etc.)
- The alignment of the interaction patterns from one domain to another

1.7 Transdisciplinary Research Process

The key characteristics of transdisciplinary research distinguishing from other related research approaches are:

- Related to real-life complex problems and specific problem solving
- Eliminate disciplinary boundaries for strong collaboration
- Participation of (non-academic) stakeholders
- Acceptance of diverse perspectives, problem framing, and interpretations
- Holistic (non-reductionist) approach to produce new knowledge for solving specific problems (transformative knowledge)

Figure 1.17 shows the proposed TD research process model, which is hypothesized in three phases: 1) team-building and collaboratively understanding of the research problem to develop collective intelligence, 2) Decomposing complex issues, 3) Transdisciplinary assessment and knowledge integration.[43]

1.7.1 Team Building and Collaboratively Understanding of the Research Problem

Transdisciplinary teams can be created with distributed leadership − research team leadership can alteration in accordance with the specific expertise required for the project in question. Often, developing and understanding a complex problem may become difficult − collaborating team members may not even agree on what the problem is and no solution can make everyone happy.[44]

Interactive Collective Intelligence Management Workshop: Using any communication platform, an ICIM workshop can be organized where research teams will introduce the

[43]Ertas, A., Rohman, J., Chillakanti, P., Baturalp, T. B. Transdisciplinary collaboration as a vehicle for collective Intelligence: a case study of engineering design education. *International Journal of Engineering Education*, Vol. 31 No.6(A), pp. 1526-1536, 2015.

[44]Denning, P. J. Mastering the Mess. *Communications of the ACM*, Vol. 50, No. 4, pp. 21–25, 2007.

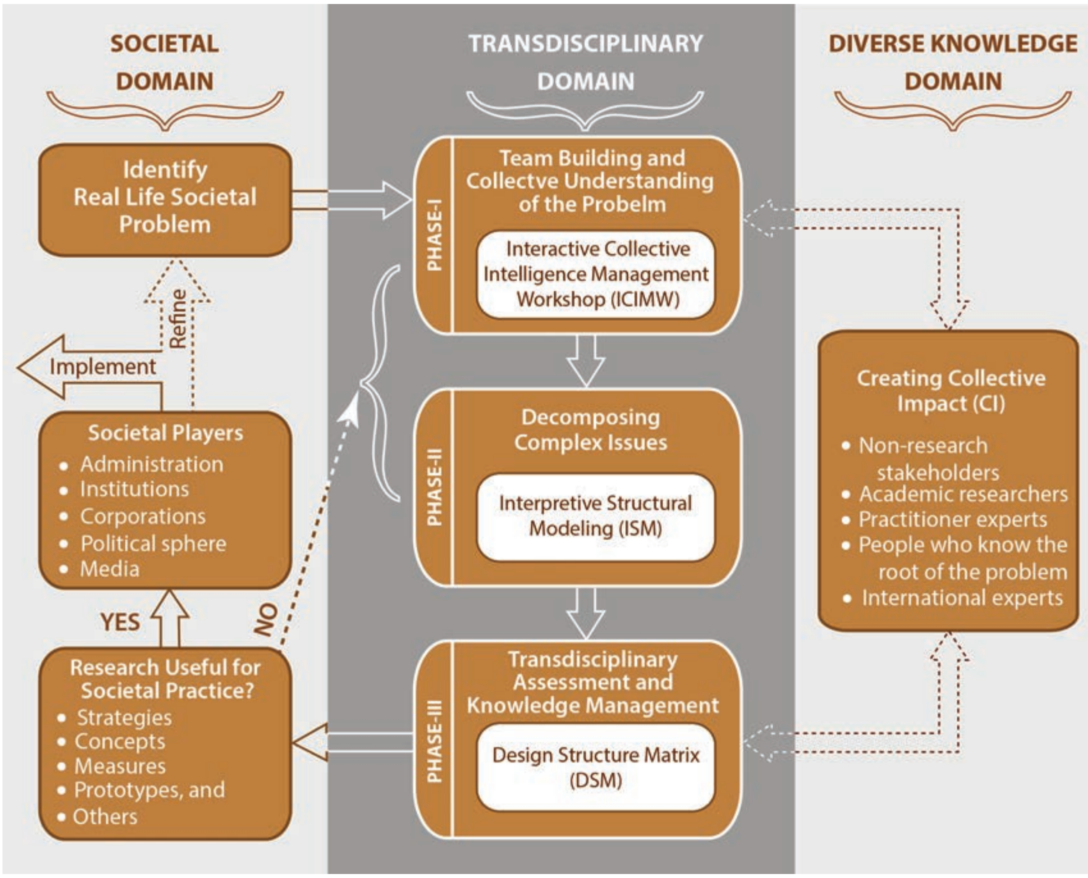

Figure 1.17: Transdisciplinary research process (adapted from [11]).

project proposals (concepts) about the complex problem being investigated. Using expert guidance from diverse knowledge domains, through dialog, the collective best ideas of research teams will come out and the incorrect or vague ideas that the research team held at the outset will be recognized as wrong or will be sharpened to make them useful.

1.7.2 Decomposing Complex Issues

Through the ICIM workshop process,[45] ideas with high interaction will be grouped into clusters. Thus, research team members can identify and examine cluster interactions internally and interactions between clusters. Decomposed complex problem clustering will be placed in a sequence

[45]Warfield, J. N., and Cardenas, A. R. *A handbook of interactive management.* Iowa State University Press/AMES, 1994.

by using a transdisciplinary tool called Interpretive Structural Modeling (ISM).[46]

1.7.3 Transdisciplinary Assessment and Knowledge Integration.

Transdisciplinary Assessment (TA) embraces integrating people (social), artifacts (technical), and knowledge (cognitive) related to different technical and non-technical knowledge domains[47] into an appropriate methodology.[48] Societal players who are involved with the problem must be included in the research process to effect scientifically valid research (see Figure 1.17).

Data will be collected using the Design Structure Matrix (DSM). Team-based DSM is used for information flow between team members or teams.[49] The following possible ways of information flow will be obtained [15]:

- Level of Detail – Sparse (Documents, e-mail) to rich (models, face-to-face)
- Frequency – Low (batch, on-time) to high (on-line, real)
- Direction – One-way to two-way
- Timing – Early (preliminary, incomplete, partial) to late (final)

If the results of the transdisciplinary assessment provide useful research for societal practice then the research outcome will be implemented otherwise TD process will repeat itself as shown in Figure 1.17.

1.7.4 Creating Collective Impact

The diverse knowledge domain shown in Figure 1.17 is the guidance of subject matter experts to create collective impact (CI) to solving social problems. Collective Impact is the commitment of cross-sector collaboration from different sectors (see Figure 1.17). It is an innovative TD approach to tackle unstructured problems by crossing professional and societal domains.

Utilizing TD methods and tools, research team members will learn: how to become more creative and discover new innovation methodologies; how to decompose unstructured complex problems to understand how various parameters relevant to the problem are interrelated; how to collaborate on achieving collective results; how to hold each other accountable for delivery according to their plans; how to candidly discuss conflicting ideas; how to accept critical dialogue and debate; and how to trust each other.

Through the following chapters of this book, we will introduce TD tools to design, manage or organize projects spanning diverse disciplines. Tools that will be covered are:

- Interactive Collective Intelligence Management (ICIM)

[46] Rittel, H. W. J., & Webber, M. M. Dilemmas in a general theory of planning. *Policy Sciences*, 4, 155-169, 1973.

[47] Blomberg, K-L, Eriksson, J., Svensson, J. Mapping of relations and dependencies using DSM/DMM-analysis. *Internationel la Handelshogskolan*, Hogskolan I Jonkoping, 2005.

[48] Hinkel, J. *Transdisciplinary knowledge integration: Cases from integrated assessment and vulnerability assessment*, Ph.D. thesis, Wageningen University, Wageningen, The Netherlands, 2008. ISBN 978-90-8504-825-1.

[49] Tyson R. B., (2001). Applying the design structure matrix to system decomposition and integration problems: a review and new directions. *IEEE Transactions on Engineering Management*, Vol. 48, No. 3, pp. pp. 292 - 306, 2001.

- Kano analysis
- KJ diagram
- Critical to Quality (CTQ)
- Quality Function Deployement (QFD) & House of Quality (HOQ)
- Theory of Inventive Problem Solving (TRIZ)
- Axiomatic Design (AD)
- Interpretive Structural Modeling (ISM)
- Design Structure Matrix (DSM)
- Risk Management Standard Tools

The integration of transdisciplinary tools used to solve cross-disciplinary unstructured problems is shown in Figure 1.18. Traditional design process approaches are inadequate to solve complex issues affecting the world today. In the proceeding modules, we will discuss some of the TD tools and their integration for the solution of complex problems.

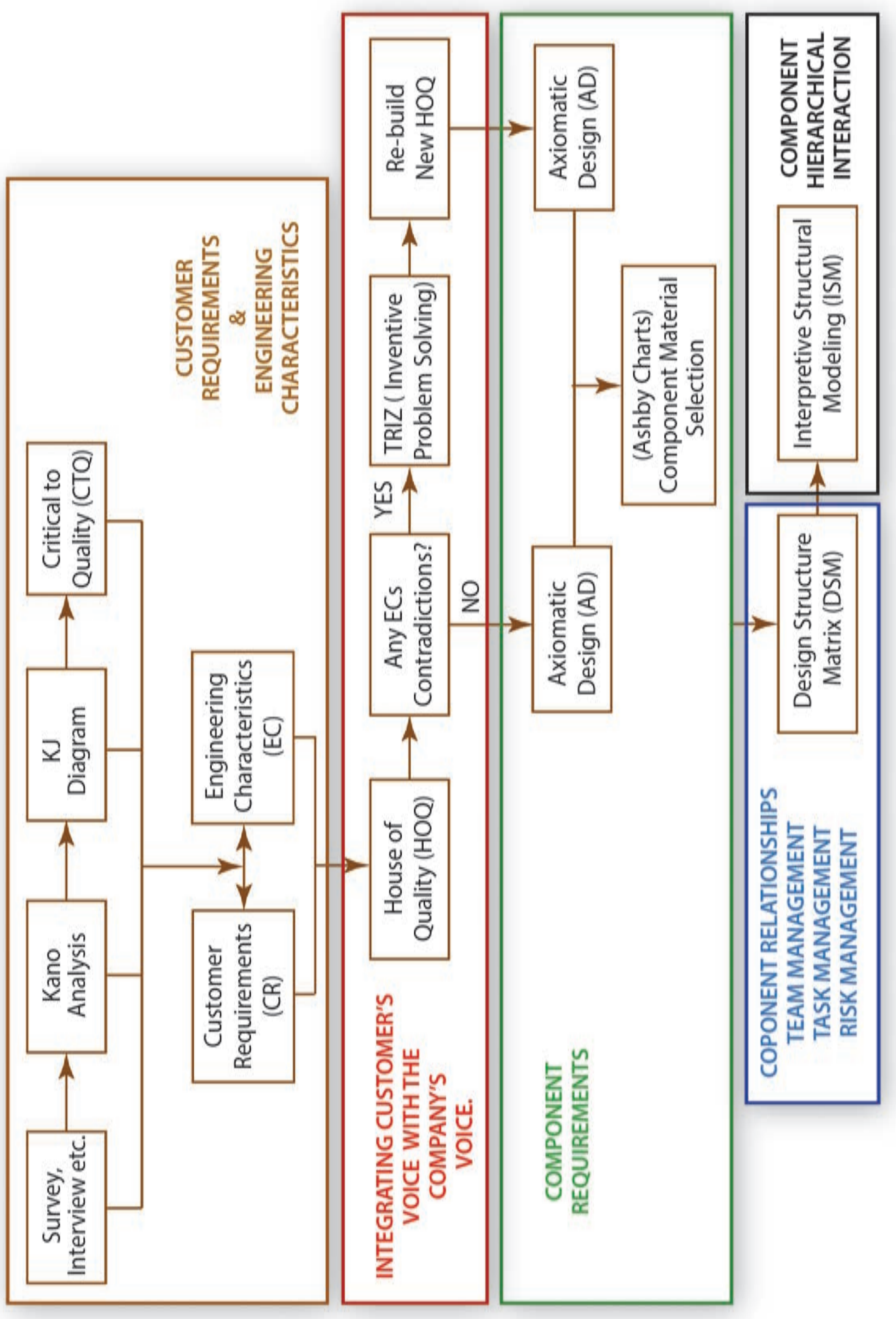

Figure 1.18: Tools for project development structure.