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Constructing Building Integrity: Raising Standards Through Professionalism

Bayesian Network Modelling

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1. Bayesian Network Modelling

1.1. Overview

Bayesian Network (BN) models were created using participatory workshops for the probabilistic operationalisation of the completed integrity system maps of each individual profession and the collection of professions servicing the construction sector. This involved taking the mapped building integrity system and empirically linking the numerous factors within that network to eventually connect to the key performance indicator (KPI) metrics for an effective profession to operate, as well as to assess all the interconnected professional relationships within the entire building industry. BNs serve as a suitable method for achieving this goal and allow for both quantitative data as well as expert opinion to be incorporated into the BN so that exploratory scenario analysis can be undertaken. Specifically, BN enabled the research team, its industry partners and critical industry stakeholder groups (e.g. EA, AIB, etc.), to explore and test the most vulnerable aspects of the current building integrity system, and to determine the most suitable and feasibly implementable combination of strategies (i.e. policy, regulation, professional development, etc.) for achieving industry performance KPIs. Ultimately, the BN model helps to ensure that the most suitable reform strategies are recommended.

1.2. Approach

The BN Workshops followed the initial interviews and thematic analysis to create the integrity system maps for each individual profession, which were later connected for the entire building industry. Participatory workshops helped to formulate the BN structure, and to populate the BN utilising historical data, where available, as well as expert opinion to populate the Conditional Probability Tables (CPTs). Once the BN and CPTs were created, subsequent workshops were completed to undertake scenario analysis, where both a forward (i.e. modifying the states of workable strategies) and backward (i.e. starting with the goals in mind by setting KPI targets for desired building industry performance) network analysis was conducted. This multi-directional analysis of the network helped researchers and industry stakeholders to better understand the causality significance between various integrity system factors, within each industry profession as well as the entire construction industry. The BN network semi-quantitatively exposed how certain actions affect others, and how a combination of fault factors can culminate in poor professional integrity and building industry outcomes. Ultimately, the scenario analysis workshops helped to frame the best combination of workable reform strategies to enhance each individual professions integrity system, as well as the overall building industry performance KPIs.

1.3. Methods for BN model development

BN is a visual tool used to model complex systems. It helps to clearly show the key factors and causal pathways in a system, document assumptions about how different elements relate to each other, and test hypotheses about how the system might respond to different changes. By combining expert knowledge, statistical analysis, and visual representation, BNs provide a powerful framework for understanding and managing complex systems.

BNs consist of three core building blocks: **1)** Variables: These represent the different factors in the system and their possible states; **2)** Links: These arrows indicate the cause-and-effect relationships between the variables, and **3)** Conditional Probability Tables (CPTs): These tables quantify the strength of these relationships.

BNs use Bayes' theorem to create a probabilistic model of a complex problem, helping to calculate the likelihood of outcomes based on causes and vice versa, all while clearly representing uncertainty. BNs are particularly useful because they can handle a variety of scenarios, predict outcomes, diagnose issues, and analyse sensitivity and trade-offs to find the best ways to reduce risks. They integrate multiple sources of information, making them versatile for different fields.

Developing a BN model involves several steps: **1)** Define Objectives: Establish what the model aims to achieve and who will use it; **2)** Conceptual Model: Create an initial diagram showing influences (**Figure 1a**); **3)** Build the Network: Define the states of each variable and set up the parameters; **4)** Evaluate the Model: Check how well the model works; and **5)** Scenario Analysis: Test different scenarios to see potential outcomes. When developing a BN model for this research, experts/stakeholders' consultations were crucial throughout this process to help define the system's scope, key variables, and assumptions. As empirical data was limited, stakeholder interviews, expert judgment and literature were used to fill in the CPTs. To populate the CPTs consistently, best-case, and worst-case scenarios were identified as benchmarks for assigning probabilities to other scenarios.

1.4. Extract demonstration of BN model for professional Integrity modelling

Extract findings for one of the BN models developed for one discipline is briefly explained. **Figure 1** shows a section of the final BN model that explores the professional integrity system for the disciplines of Construction Managers, Engineers, and Architects. **Figure 1a.** shows the influence diagrams created through a series of industry expert interviews and thematic analysis. These influence diagrams were converted to a BN network model (**Figure 1b.**) for subsequent model operationalisation/evaluation.

Each bar within the BN node (**Figure 1b.**) represents the probability of different states for each variable. For example, the target node, "*Professional Integrity of Housing Sector*," shows the predicted probability of being either '*Above Average*' or '*Below Average*'. The probability assigned to each state in this target node indicates the likelihood of a particular state being true. For example, the BN node named "*Professional Integrity of Housing Sector*" with two states: '*Above Average*' and '*Below Average*'. The probability calculated for '*Above Average*' is 0.45, while the probability calculated for '*Below Average*' is 0.55. In this present state scenario, the interpretation is that it's more likely (55% chance) that *Professional Integrity of Housing Sector* is below average. These probabilities are typically determined based on collected (stakeholder interviews and survey) data and expert knowledge. If, after implementing some actions or strategies to improve the systems' professional integrity, this node '*Above Average*' probability increases from 45% to say 60%, this indicates that the system is on the right track towards building a strong integrity culture in the Housing Sector.

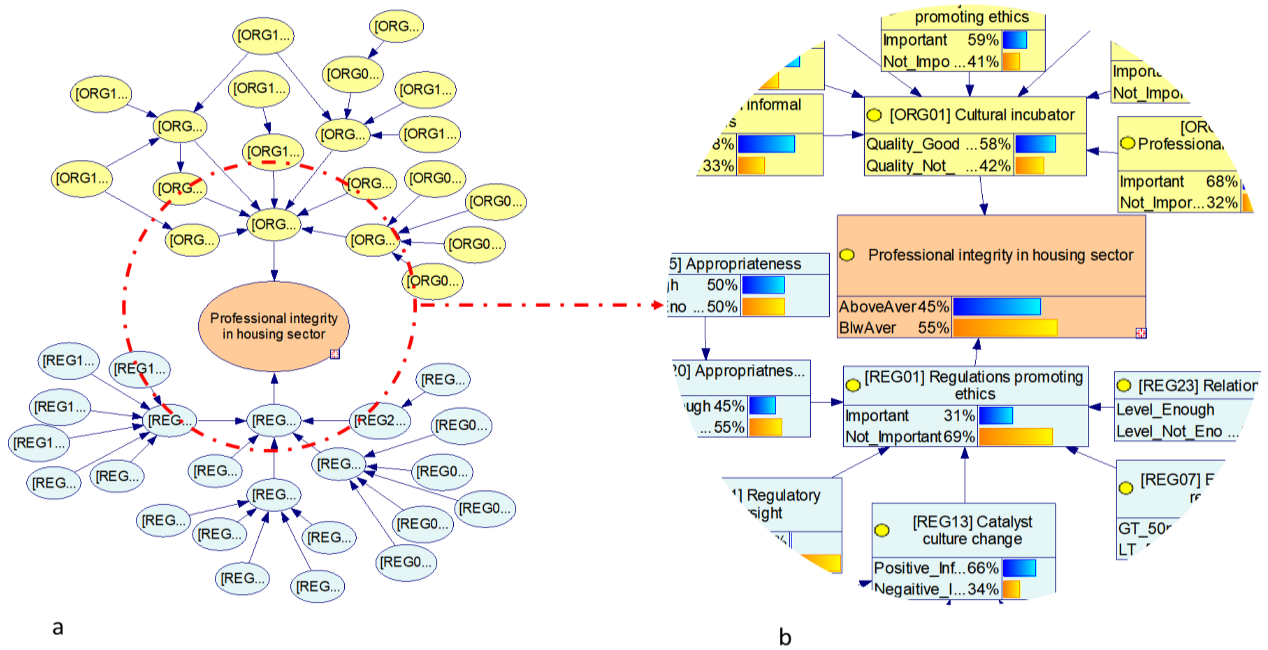

Figure 1: a) Influence diagram, and **b)** extract section of BN mode

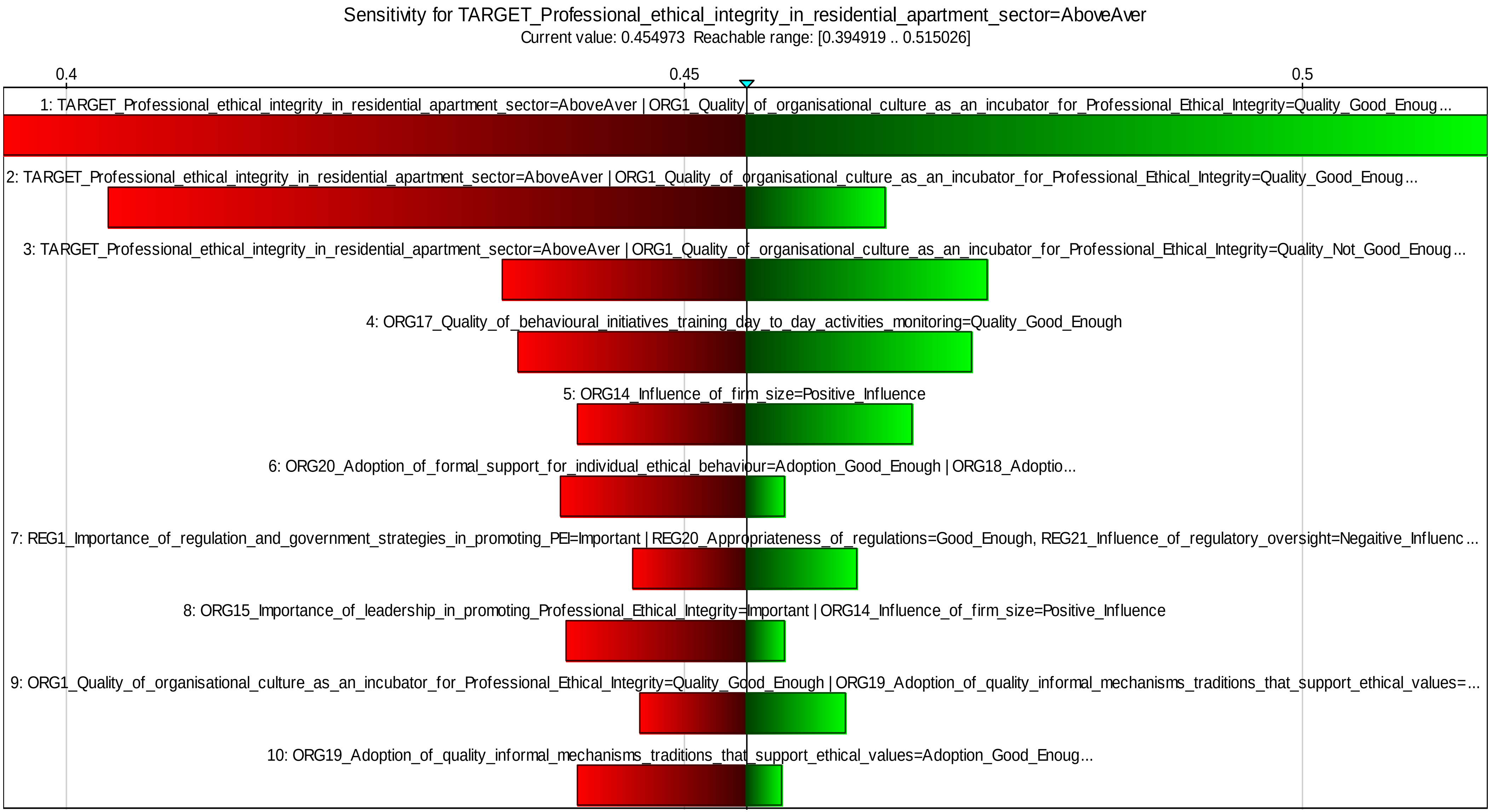

Figure 2: A tornado diagram shows how changes in individual factors (variables) can impact the overall outcome (target variable). Each bar represents a variable in the network. A tornado graph is a visual tool used to assess the sensitivity of a target variable to changes in its parent variables.

Figure 2 illustrates how changes in individual factors can affect the overall outcome. The length of the band indicates the influence that variable has on the target variable. A longer bar signifies a greater impact. The colour of the bar represents the direction of change: green for positive (increased probability) and red for negative (decreased probability). The centre line represents the baseline probability of the target variable. Variables with the longest bars have the most significant impact. For example, in our BN model (**Figure 1**), the Target Variable is *Professional integrity in housing sector* (*Above Average/Below Average*) - Baseline probability: 45% Above Average, 55% Below Average; and parent variables are Cultural incubator (*Quality Good Enough/Quality Not Good Enough*) and Regulations promoting ethics (*Important/Not Important*). For example, if the graph shows a long bar extending upwards for "*Cultural incubator: Quality_Good_Enough*," it suggests that a good quality *cultural incubator* program significantly increases the probability of "*Above Average*" professional integrity. Conversely, a long bar extending downwards for "*Regulations promoting ethics: Not Important*" would indicate that weak regulations lead to a higher probability of "*Below Average*" integrity. By analysing the lengths and directions of the bars in the tornado graph, we can identify which factors (e.g. *cultural incubator quality* or *regulations*) have a more significant impact on promoting ethical conduct in the housing sector.

1.5. BN model scenario analysis – A tool for diagnosis and prognosis

Figure 3 depicts the strength of influence between variables. The thickness of the arrows indicates the intensity of the connection between the linked elements. This strength is calculated based on the probability tables and helps us visually analyse and verify the model during construction. This visual representation helps in analysing and verifying the model during its construction.

The thickness of the arrow connecting a parent node to the target node indicates the strength of influence that parent has on the target variable's probability distribution. A thick arrow signifies a strong influence. This means the state of the parent variable significantly alters the probabilities of the target variable. A thin arrow represents a weak influence. The state of the parent has a minimal impact on the target variable's probabilities. For example, in a scenario shown in **Figure 3**, *Regulations promoting ethics* [REG01] likely have a strong influence on professional integrity. If the regulations are Important, it might significantly increase the probability of *Above Average* integrity (thicker arrow). Conversely, *Not Important* regulations might push the probability towards *Below Average* integrity. The impact of a *Cultural incubator* [ORG01] might be weaker. Even with a *Good Enough quality incubator*, integrity might still struggle if regulations are weak. A *Not Good Enough incubator* might nudge integrity downward, but the effect might be less pronounced (thinner arrow).

By visually highlighting the strength of these relationships, the Strength of Influence diagram provide a quick visual assessment of which factors have the most significant impact on the target variable. This helps decision-makers prioritise interventions. In this case, focusing on strengthening the *cultural incubator* program might have a more significant impact on professional integrity compared to regulations alone. For example, if the *cultural incubator* has a strong positive influence, efforts to improve its quality might be more impactful than strengthening regulations (given the arrow for regulations is relatively thinner).

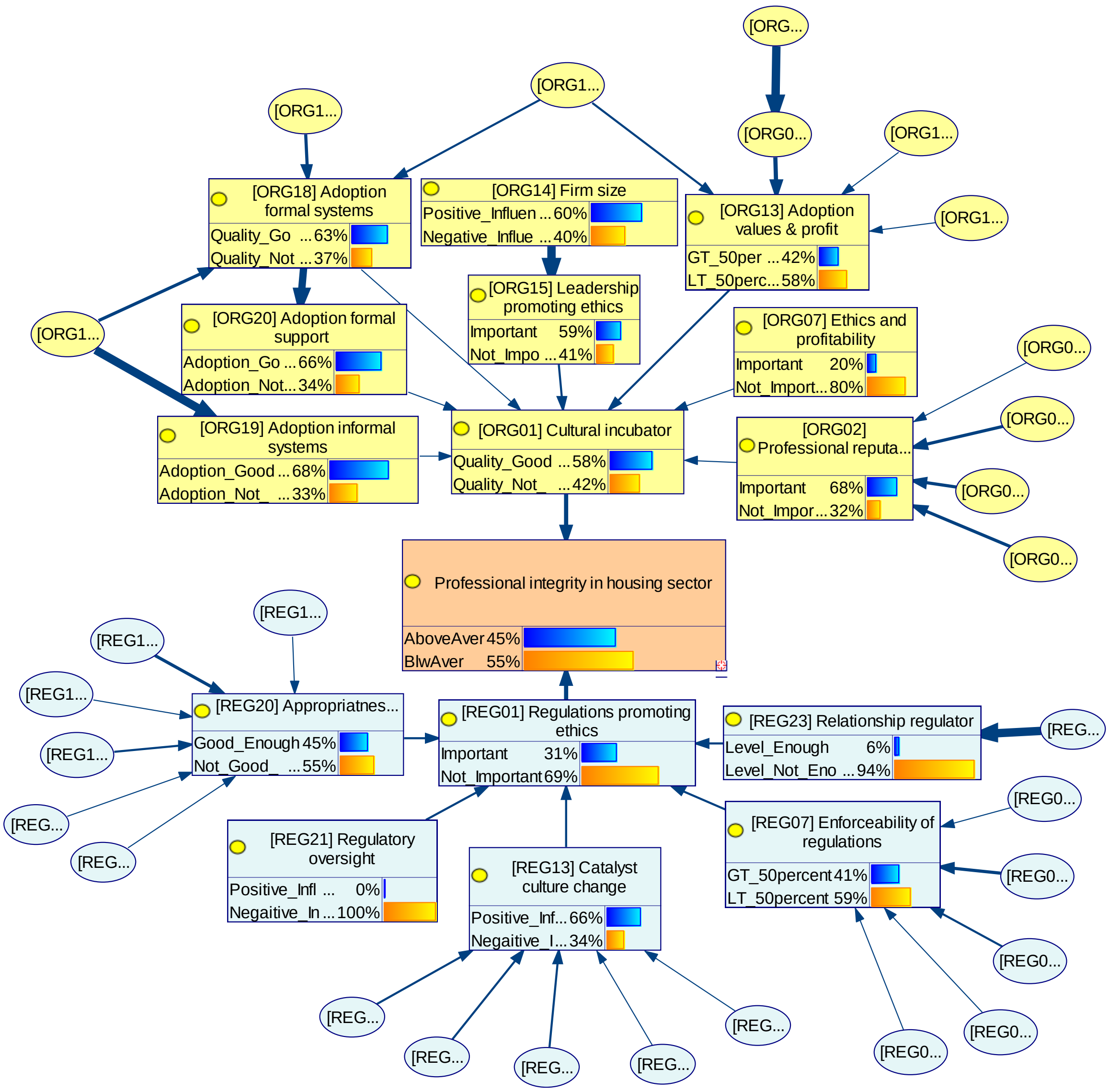

Figure 3: Strength of influence diagram depicts strength of influence between factors (nodes)

1.6. Summary

BN is a good tool to semi-quantitively model the Australian building industry integrity system. The BN network explored how certain actions affect others, and how a combination of inhibiting factors can lead to poor professional integrity, and undesirable building industry outcomes. A key advantage of BN modelling over soft-systems mapping is that it can empirically determine the most suitable and feasibly implementable combination of strategies (i.e. policy, regulation, professional development, etc.) for achieving industry performance KPIs (e.g. fewer building defects). Beyond selecting suitable planning strategies, a fully operationalised BN dashboard for scenario analysis creates industry engagement and buy-in to implement a fit-for-purpose strategic pathway to the desired outcomes.