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HOW DO DIFFERENT MINDS SHAPE PERFORMANCE IN CONSTRUCTION? AN AGENT-BASED MODELLING APPROACH

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ABSTRACT

In the dynamic construction industry, project performance crucially depends on the cognitive diversity of team members. The varied cognitive abilities across teams significantly influence their adaptability and efficiency, driving the success of construction projects in unpredictable and dynamics environments. This paper employs an Agent-Based Modelling approach to explore how variations in cognitive abilities, improvisation, collaboration, and physiology-related, affect project outcomes. By simulating real-world construction scenarios, the model examines the effects of cognitive trait diversity on decision-making and team dynamics. This study aims to uncover the complex relationship between cognitive diversity and project performance, highlighting its impact on the efficacy of solutions and collaborative efforts. The findings provide valuable insights into optimizing team composition and enhancing decision-making processes in construction projects. Ultimately, this research advances our understanding of how cognitive factors influence project success, offering strategies to foster more resilient and effective construction teams.

1 INTRODUCTION

The construction industry, known for its complex and dynamic nature, requires not only robust physical infrastructure (Abdelhamid and Everett 2002) but also the collective cognitive competence of its workforce to navigate the inherent unpredictable challenges (Dadi et al. 2014). In this milieu, the cognitive abilities of team members, ranging from engineers and managers to frontline workers, play a pivotal role in the success of construction projects (Mitropoulos and Cupido 2009).

Recent research in the field has begun to shed light on the importance of cognitive diversity in construction teams. Studies have highlighted the advantages of various human factors, including cognitive skills, including improvisational abilities (Hamzeh et al. 2018), collaborative capabilities (Schöttle et al. 2014), and physiological abilities (Abdelhamid and Everett 2002) in enhancing team performance and project outcomes. Improvisation is defined as “the act of dealing with the unexpected without having the luxury of preparation.” (Hamzeh et al. 2019). This definition inherently highlights the importance of project members’ cognitive abilities in addressing unexpected challenges through spontaneous decision-making and creative problem-solving. These abilities enable teams to adapt to changing conditions and formulate effective responses to unforeseen obstacles, ultimately ensuring project continuity and efficiency. In fact, several studies have attempted to investigate the impacts of improvisational skills of construction members on project outcomes (Alhussein et al. 2022; Hamzeh et al. 2012, 2018, 2019). On the other hand, collaboration in construction is deemed indispensable (Schöttle et al. 2014), requiring specific cognitive abilities that facilitate effective communication, shared understanding, and cooperative problem-solving among diverse team members. These abilities enable project members to integrate their specialized skills and knowledge in a concerted effort to achieve common project goals, enhancing the overall productivity and success of construction projects (Thomson et al. 2009). Furthermore, physiological abilities are essential to any construction project, as they directly impact the capacity of workers to perform labor-intensive tasks efficiently and safely. The physical demands of construction work, such as strength, stamina, and dexterity, are critical factors that influence not only the execution of tasks (Abdelhamid and Everett 2002), but also the overall project management and engineering processes. These physical attributes are essential for managers and engineers who need to actively navigate construction sites, assess the progress and quality of work in real-time, and engage directly with workers and materials (Hasanzadeh et al. 2017). Robust physiological attributes allow workers to maintain high levels of performance throughout the demanding schedules of construction projects, minimizing the risk of injuries and accidents. Studies have shown that enhancing physiological attributes through proper training, ergonomic practices, and health management can significantly improve project outcomes by reducing delays and increasing worker satisfaction and productivity (Abdelhamid and Everett 2002).

Numerous studies have addressed the aforementioned factors and their impacts on construction projects outcomes. However, there remain notable gaps in the literature: (1) the integration of various cognitive abilities required for the aforementioned factors to explore their impacts on project performance, and (2) the systematic quantification of cognitive diversity's impact on construction project performance, particularly in relation to the varying demands of construction tasks.

This paper aims to fill this gap by developing an Agent-Based Model (ABM) that simulates the interplay between team members' cognitive diversity and project outcomes. By integrating a range of cognitive abilities and their measurements into the ABM, this study provides a predictive framework that can inform strategic team assembly and project management decisions.
The objectives are twofold: firstly, to conceptualize and implement an ABM that includes the key cognitive attributes required for construction projects, and secondly, to analyze the effects of these attributes on project performance through a series of simulated scenarios. This methodology allows for an empirical investigation that can highlight the potential for cognitive alignment to enhance project success.

The paper is structured as follows: a comprehensive literature review is carried out to explore the different cognitive abilities needed in construction, particularly, for improvisation, collaboration and physiology, all of which are necessary on construction projects among engineers, managers, and workers. Afterwards, means for measuring these abilities are explored, to later be used as inputs for the developed model. Then, the research methodology is presented, followed by a detailed explanation of the development of the model and its agents, along with its verification. Afterwards, an illustrative example is presented with its results and their implications, followed by a conclusion that encapsulates the study's contributions, limitations, and avenues for future research.

2 LITERATURE REVIEW

The literature review section in this paper covers the cognitive abilities needed in construction, particularly for improvisation, collaboration and physiology. Then, means for measuring these abilities are explored, where project members' cognitive abilities will later be used as model inputs, calculate project outcomes.

2.1 Cognitive Abilities for Decision-Making in Construction

Effective decision-making in construction relies heavily on a comprehensive blend of cognitive and physiological abilities. Drawing upon the Cattell-Horn-Carroll (CHC) (McGrew 2009) model, this study outlines a comprehensive array of abilities pertinent to improvisation, collaboration, and physiology within construction contexts, as previously established (Shehab and Hamzeh 2024). These abilities are not merely beneficial but fundamental to navigating the complexities and dynamism inherent in construction projects.

First, regarding improvisation, which is necessitated by unforeseen challenges in construction projects, it involves 25 cognitive abilities as categorized by the CHC model. These include but are not limited to: (1) originality/creativity: essential for devising innovative solutions when faced with limitations or constraints; (2) ideational fluency: The capacity to produce numerous ideas and solutions within a short timeframe; and

(3) visualization: The ability to mentally manipulate, rotate, and transform visual patterns, which is crucial for modifying project plans on-the-fly.

As for collaboration within the construction industry, it is contingent on cognitive abilities that facilitate joint efforts towards a common goal. Five key abilities, informed by the CHC model are:

- Communication Ability: Encompassing both verbal and non-verbal communication skills, as well as the capacity to empathize and build rapport.
- Knowledge of Behavioral Content: Enables effective teamwork by navigating group dynamics.
- Listening Ability: A specific aspect of comprehension, crucial for the mutual understanding that underlies collaborative work.
- Expressional Fluency: The cognitive ability to convey ideas verbally rapidly and effectively, including the ease of producing coherent, structured, and persuasive speech.
- Word Fluency: The cognitive ability to effortlessly produce a rapid succession of words.

Finally, the practical application of decision-making in construction demands physiological abilities to execute cognitive decisions. Eleven physiological abilities, grounded in the CHC framework, include:

- Finger Dexterity: Precise control over finger movement, crucial for handling tools and materials with detail and accuracy.
- Manual Dexterity: The skillful manipulation of objects with hands, vital for various construction tasks.
- Control Precision: The ability to adjust the controls of equipment and machinery quickly and accurately.
- Arm-Hand Steadiness: The steadiness and precision of arm-hand movements, necessary for tasks that require meticulous control and stability.

2.2 Measuring Cognitive and Physiological Abilities

After identifying the cognitive abilities that are critical in construction, the measurement of cognitive and physiological abilities is key for effective decision-making in construction. Two main methods for measuring abilities are detailed in this study: wearable sensor technologies and cognitive assessment tests.

2.2.1 Wearable Sensors for Cognitive and Physiological Measurements

Advancements in wearable technologies have provided tools that can measure both cognitive statuses through brain activity, eye metrics, and skin responses, and physiological statuses through cardiovascular measures and muscle activity (Shehab and Hamzeh 2023).

Cognitive status measurements include (1) brain activity, where electroencephalogram (EEG) devices are pivotal for measuring mental states like stress, fatigue, and arousal by capturing brain's electrical activity, which are crucial for assessing cognitive load and the ability to handle tasks requiring improvisation and collaboration (Giannakakis et al. 2019); (2) eye-tracking technologies that measure blink rates, fixation times, and pupil diameters, which are indicators of cognitive load and attention. These metrics are essential for evaluating situational awareness, a key component in collaborative and improvisational abilities (Hasanzadeh et al. 2017); and (3) skin response measurements such as skin temperature and electrodermal activity (EDA) that provide data on emotional and stress responses, reflecting the cognitive burden under challenging scenarios (Giannakakis et al. 2019).

As for physiological status measurements, they include (1) cardiovascular measures through devices that monitor heart rate and heart rate variability through electrocardiograms (ECG) and photoplethysmography (PPG) that offer insights into physical stress and exertion levels. These measures help assess the physiological capacity needed for tasks demanding physical endurance (Giannakakis et al.

2019); and (2) muscle and limb activity, such as Inertial Measurement Units (IMU) and electromyograms (EMG) track movements and muscular activity, which are essential for determining the physical demands placed on workers during construction tasks. These sensors evaluate the physiological abilities related to tasks requiring manual dexterity and physical stamina (Al-Qaisi et al. 2021).

2.2.2 Cognitive Assessment Tests

While wearable sensors effectively measure physiological responses, cognitive assessment tests are crucial for directly measuring cognitive abilities relevant to decision-making. These tests can be administered in various formats, including digital platforms or traditional paper-based methods, depending on availability and context. Key cognitive abilities such as problem-solving, memory, attention, and spatial reasoning can be evaluated through standardized tests, providing a comprehensive profile of a worker's cognitive capacity. These assessments are integral for identifying strengths and weaknesses in individual and team cognitive profiles, informing team compositions, and training programs aimed at enhancing cognitive skills crucial for construction tasks.

3 METHODOLOGY

This paper adopts an Agent-Based Modelling (ABM) approach to investigate the relationship between cognitive abilities and project performance in construction projects. An ABM is a computational modeling technique used to simulate the behavior of autonomous agents within a defined environment (Macal and North 2009). These agents possess individual characteristics, interact with each other and their surroundings, and exhibit emergent behavior, allowing researchers to study complex systems and phenomena (Macal and North 2009). ABM was selected as the main methodology for this study because of its ability to capture the dynamic and interactive nature of construction projects. By modeling individual agents with distinct cognitive abilities and simulating their interactions within the construction environment, ABM provides a refined understanding of how cognitive diversity influences project performance. This approach allows for the exploration of emergent phenomena arising from the collective behavior of agents, offering insights into optimizing team composition and decision-making processes to enhance project outcomes in a complex and evolving industry like construction.

The steps followed in this methodology are (1) conducting literature review investigating the cognitive abilities needed for construction-related decision-making processes, such as improvisation, collaboration, and physiology. Additionally, ways for measuring these abilities are explored. Next, (2) the agent-based model is developed by designing the environment and agents and assigning the attributes of all agents along with their behaviors, states, and interactions. (3) The mathematical models describing the outcomes of the model are then presented, and (4) model verification is performed. (5) An illustrative example with sample data is fed into the model to be able to simulate various scenarios and obtain model results. (6) Analysis and discussions on the model are then carried out, followed by (7) recommendations and conclusions.

4 MODEL DEVELOPMENT

This research develops generic ABM designed to simulate the dynamic interactions within a construction project environment. The model is structured around two primary agents populations: project members and issues - that interact within this simulated construction setting. The purpose of this ABM is to explore how various cognitive and physiological abilities impact project outcomes when confronted with real-world challenges.

4.1 Model Environment

The environment within the model represents a construction project, characterized by its dynamic nature and the continuous evolution of project needs and challenges. This simulated environment is designed to mimic the complexities and unpredictability of actual construction projects, providing a realistic backdrop against which agent interactions occur. Key environmental factors include the project timeline, resource availability, and external conditions that can affect project execution.

4.2 Agent Populations

The model includes two distinct populations of agents, each with specific attributes and characteristics:

4.2.1 Project Members Agents

These agents represent the human resources involved in the construction project. Each project member is modeled with unique cognitive and physiological profiles, derived from the measurement data discussed earlier. These profiles influence their performance and interactions within the project environment. Project members are tasked with various construction activities and must respond to issues as they arise, utilizing their cognitive and physiological abilities to navigate and solve problems. Table 1 shows the different attributes assigned to each member agent. Improvisation, collaboration, and physiology-related cognitive abilities are inserted into the model as inputs after being measured through the two methods explored previously in the literature review section.

Table 1: Members agent attributes.

Members Attributes	**Source**
ID	Unique member ID number
Improvisation-related cognitive abilities	Measurement through sensors or tests
Collaboration-related cognitive abilities	Measurement through sensors or tests
Physiology-related cognitive abilities	Measurement through sensors or tests

The following section describes the flow of each member agent through the different states of the project.

- Initial State: **Working**. Project members start in the "Working" state, indicating they are currently working on a task with no issues to deal with.
- Transition to **'Identifying Issue'**: When an issue arises within the project environment, one member is randomly assigned to this issue and transitions from "Working" to "Identifying Issue." This state reflects the cognitive process of recognizing and assessing a new challenge or problem that needs to be addressed.
- Decision Point: *Assignment style*. If the assignment style of the issue is optimal, only workers with cognitive abilities that match the issue’s cognitive demands are assigned to deal with this task. If the assignment style is random, any worker, regardless of their abilities, is assigned to the issue.

ASSIGNMENT STYLE 1: optimal:

- Decision Point: *Eligibility*. Members evaluate their ability to address the issue based on their cognitive and physiological profiles.
- **Ineligible**: If a member lacks the necessary abilities (i.e. cognitive and physiological skills of member are less than cognitive and physiological demands of issue), they transition to the "Ineligible" state, search for another member who can potentially address the issue, and return to “Working", awaiting new issues.
- **Eligible**: If a member possesses the required abilities (both cognitive and physiological) to potentially resolve the issue, they move to the "Eligible" state.

- Resolution Pathways for Eligible Members. Members evaluate if the issue at hand requires one member (themselves) or more members.
- **Resolving Alon**e: If the issue requires only one member to handle it, this member transitions to "Resolving Alone."
- **Building Team**: If the issue requires more than one member, the agent moves to "Building Team." This state involves collaborating with other members to form a team that collectively possesses the requisite skills. In this state, the members start assigning new eligible members to join the team for addressing the issue. After assigning each new member, the responsible member evaluates if more members are required (i.e., team size is less than the issue's required number of workers) or not.
- **Resolving Collaboratively**: Once a team is formed, members work together in the "Resolving Collaboratively" state.

ASSIGNMENT STYLE 2: random

In this assignment style, any member is assigned to handle the issue, regardless of their cognitive and physiological abilities. The number of members required to handle the issue is also disregarded. Therefore, in this case, the eligibility decision point is skipped, and members randomly decide whether they will work alone or build a team. Therefore, for random assignments, the "Eligible" and "Ineligible" states are never entered, and the "Resolving Along" and "Building Team" states are entered randomly.

4.2.2 Issues Agents

The second type of agent represents the challenges or problems that spontaneously arise during the construction process. These issues vary in nature and complexity, ranging from material shortages and equipment failures to unexpected design changes or weather-related disruptions. Each issue requires specific cognitive and physiological responses from the project members, putting their improvisation, collaboration, and physical capabilities to the test. Table 2 shows the different attributes assigned to each issue agent.

Table 2: Members agent attributes.

Issues Attributes	Source
ID	Unique issue ID number
Improvisation-related cognitive demands	Project historical data or surveys
Collaboration-related cognitive abilities	Project historical data or surveys
Physiology-related cognitive abilities	Project historical data or surveys
Required number of members	Project historical data

Flow of Issue Agents Through Different States:

Initial State: **Inexistent**. Issues start in the "Inexistent" state, indicating that they have not yet arisen or been identified within the project environment.

Transition to **'Arose'**: When certain conditions within the project environment trigger the emergence of an issue, it transitions from "Inexistent" to "Arose." This state change signals the recognition and activation of the issue within the ABM, ready to be addressed by the project members.

Response to Issue: Assessment of Issue: Upon arising, each issue is assessed to determine its complexity and the demands it places on the project members. This assessment includes reviewing the improvisation, collaboration, and physiological demands, along with the number of members required to resolve the issue effectively.

Seeking Resolution: The issue remains in the "Arose" state while project members are being assigned and are working to resolve it. The progression from this state depends on the interaction with project members: If the project members successfully address the demands of the issue with their combined abilities, the issue transitions to the "Resolved" state. This outcome indicates that the challenge has been adequately managed, and the issue is considered closed. If the issue is resolved but with inefficiencies such as excess resource consumption or extended time, it transitions to "Resolved with Waste." This state suggests a suboptimal resolution that, while effective, resulted in wasted resources or effort. Finally, if the issue is not resolved satisfactorily, either due to inadequate member abilities or insufficient collaboration, it remains in the "Unresolved" state.

4.3 Scores and Project Outcomes

In this study, project outcomes are critically determined by the scores of the project members or teams assigned to resolve issues. These scores, derived from a mathematical formula, quantify the effectiveness of the members in handling tasks based on their cognitive abilities and the alignment of team composition with the task requirements. The score for each member or team is calculated using a formula that integrates the cognitive abilities essential for construction tasks—improvisation, collaboration, and physiology—with the adequacy of the number of workers assigned relative to the number required by the task. The formula is structured as follows:

$$Score = (\alpha \cdot CI_{imp} + \beta \cdot CI_{coll} + \gamma \cdot CI_{phys}) \times Match_{num} \quad (1)$$

where:

- CIimp: Cognitive Index for improvisation ability of the member (or average for team members).
- CIcoll: Cognitive Index for collaboration ability of the member (or average for team members).
- CIphys: Cognitive Index for physiological ability of the member (or average for team members).
- Matchnum: A coefficient that represents the match between the number of workers on the team and the number required by the task. This value adjusts the score based on whether the team size is optimal, insufficient, or excessive relative to the task's demands.
- α, β, γ: Weighting factors that reflect the relative importance of each type of cognitive ability for the task at hand.

These parameters are pre-defined based on empirical data and expert input to reflect the complexity and nature of construction tasks.

The score calculated for each issue-handling attempt directly influences the outcome of that issue within the project environment. There are three potential outcomes for each issue, as previously described by (Alhussein et al. 2022): (1) **Resolved**: This outcome occurs when the score exceeds a predefined threshold indicating that the team or member has sufficiently addressed all aspects of the issue effectively; (2) **Resolved with Waste**: If the score falls within a moderate range, the issue is resolved but not optimally. This outcome suggests that while the task is completed, there has been inefficiency in resource use or time, leading to waste. This typically happens when the team size does not perfectly match the task requirements or if the cognitive abilities, though adequate, are not ideally suited for the task specifics; (3) **Unresolved**: A low score leads to this outcome, where the issue remains unresolved. This indicates that the team or member was unable to meet the task's demands, likely due to a significant mismatch in cognitive abilities or insufficient team size.

5 MODEL VERIFICATION

Verification of the proposed model was conducted to ensure the accuracy and reliability of the model, using the methodology recommended by (Sargent 1992). This process is crucial for validating the structural integrity and output accuracy of the simulation under a range of scenarios.

5.1 Extreme Condition Tests

The first verification method employed was the Extreme Condition Tests, which examine the plausibility of the model's structure and output under highly improbable conditions. For this model, extreme scenarios included situations where: (1) all project members possess maximum cognitive abilities in improvisation, collaboration, and physiology; (2) issues arising are of the lowest complexity requiring minimal cognitive or physiological effort to resolve; and (3) resources are abundant and environmental constraints are minimized. Under these conditions, the model showed that project outcomes were exceptionally positive, with issues being resolved promptly and efficiently, closely aligning with the ideal productivity scenarios.

5.2 Degenerate Tests

Degenerate Tests were also performed to assess the model's response to adverse conditions. In these tests, the model was adjusted to reflect scenarios with negative impacts, such as (1) project members with low cognitive abilities; (2) high complexity issues with significant demands on both cognitive and physiological resources; and (3) environmental and resource constraints that typically hinder project progress, like resource scarcity. The model was expected to demonstrate increased difficulty in resolving issues, resulting in delays and inefficiencies. The outcomes confirmed that the number of unresolved or inefficiently resolved issues increased, validating the model's sensitivity to changes in input parameters and internal conditions.

5.3 Illustrative Example

An illustrative example was applied to further test the logic and reliability of the model. This example involved a simulated construction project with predefined variability in team cognitive abilities and a series of issues with varied complexities. The simulation tracked how effectively different teams addressed these issues and the overall impact on project timelines and quality. The results demonstrated consistency with expected outcomes based on the cognitive profiles of the teams and the nature of the issues, underscoring the model's practical applicability and reliability.

6 ILLSUTRATIVE EXAMPLE RESULTS AND DISCUSSION

This section provides an in-depth analysis of the verification process applied to the model developed to study cognitive diversity in construction project teams. Utilizing illustrative examples, the model's capabilities and reliability are demonstrated by simulating scenarios where both issue requirements and workers' abilities are generated through random distributions. This approach ensures a robust testing environment that mirrors the unpredictable and varied nature of real-world construction projects.

In order to validate the model and its applicability to real-world construction management scenarios, a series of 100 simulation runs were conducted. These runs were evenly split between the two assignment strategies to test the model's response under varying operational tactics: 50 simulations employed a random assignment of workers to issues, and 50 simulations utilized an optimal assignment strategy where workers' cognitive abilities were ideally matched to the issues' requirements.

This dual-strategy approach allows us to dissect the impact of assignment precision on project outcomes, particularly focusing on how well issues are resolved under each scenario. The random assignment strategy reflects a more chaotic and less controlled environment which might occur in real-life projects due to unexpected changes or lack of information. Conversely, the optimal assignment simulations provide insights into the potential enhancements in project performance when team compositions are meticulously aligned with task demands based on cognitive and physiological capabilities.

The results from these simulations are critical in understanding the benefits of strategic team assembly and the drawbacks of random assignments. By comparing these two methodologies, we aim to highlight the significance of cognitive alignment in project teams and its influence on the efficiency and success of construction projects.

For each simulation run, the following metrics were calculated:

- Number of resolved issues
- Number of issues resolved with waste
- Number of unresolved issues
- Percentage of unsuccessful issues = (Resolved issues + Resolved with waste) × 100 / Total issues
- Average score of all issues completed
- Percentage of good improvisors (members with improvisation ≥ required improvisation skills)
- Percentage of good collaborators (members with collaboration ≥ required collaboration skills)
- Percentage of good physiology members (members with physiology ≥ required physiology)
- Percentage of issues completed with enough members (number of members assigned to an issue is equal to or greater than the number of members required by that issue)

Table 3 represents a summary of simulation outcomes based on assignment style, where the Random Assignment column represents statistics derived from the first 50 simulation runs with random assignments of workers to issues, the Optimal Assignment column represents statistics derived from the latter 50 simulation runs with optimal assignments, where workers' abilities are ideally matched to the issue requirements, and the Difference column is calculated as the difference between the Optimal and Random assignment outcomes to illustrate the impact of strategic team composition.

Table 3: Summary of simulation outcomes based on assignment style.

Metric	Random Assignment	Optimal Assignment	Difference
Average Resolved Issues	2.58	20.00	+17.42
Average Resolved with Waste	13.26	0.00	-13.26
Average Unresolved Issues	4.16	0.00	-4.16
Average % of Unsuccessful Issues	87.10%	0.00%	-87.10%
Average Scores	0.577	1.00	+0.423
Average % of Good Improvisors	58.43%	100.00%	+41.57%
Average % of Good Collaborators	60.60%	100.00%	+39.40%
Average % of Good Physiology	59.27%	100.00%	+40.73%
Average % of Enough Workers	37.30%	100.00%	+62.70%

Figure 1 displays a series of scatter plots illustrating the relationships between team performance scores and various cognitive and physiological team attributes for the random assignment strategy in the Agent-Based Model simulations. Each plot shows data points that represent outcomes of individual simulation runs, capturing the correlation between the team's average performance score and the percentage of team members who excel in improvisation, collaboration, physiology, and overall team size adequacy. The regression lines suggest the predictive power of each attribute on team success.

The first plot reveals an upward trend, where a higher percentage of good improvisors correlates with improved performance scores, an indication of improvisation's pivotal role in resolving construction issues. This trend, quantified by an R^2 value of 0.2761, suggests that improvisational skills are a strong predictor of success, accounting for about 28% of the variability in scores. The second plot demonstrates a positive correlation between good collaborators and performance scores, with an R^2 value of 0.1512, indicating that collaborative skills account for approximately 15% of the performance variability. This relationship highlights the value of teamwork and cooperative skills in achieving project goals. The third plot also indicates a positive trend, with an R^2 value of 0.1748, implying that physiological strength accounts for about 17% of the variance in scores. This underscores the importance of physiological attributes in managing the physical demands of construction tasks. The final plot echoes the importance of adequate team size, with the same R^2 value of 0.1748, reinforcing that having enough team members is as crucial as their physiological capabilities in determining team performance.

For optimal assignments, each attribute percentage reaches the maximum, reflecting perfect alignment with project demands and resulting in uniformly high-performance scores. However, the scatter and spread of data points in the random assignment plots reflect the real-world challenges of team composition, where the inherent unpredictability can lead to variable outcomes. These visual trends not only affirm the importance of each attribute in achieving project success but also showcase the need for strategic team composition that balances all key cognitive and physiological abilities.

The integrated analysis from Figure 1 serves as a powerful narrative on the composite nature of team competencies necessary for optimal construction project execution. It emphasizes that while individual cognitive and physiological skills are essential, the collective alignment of these attributes within a team setting is paramount for navigating the multifaceted challenges inherent in construction projects.

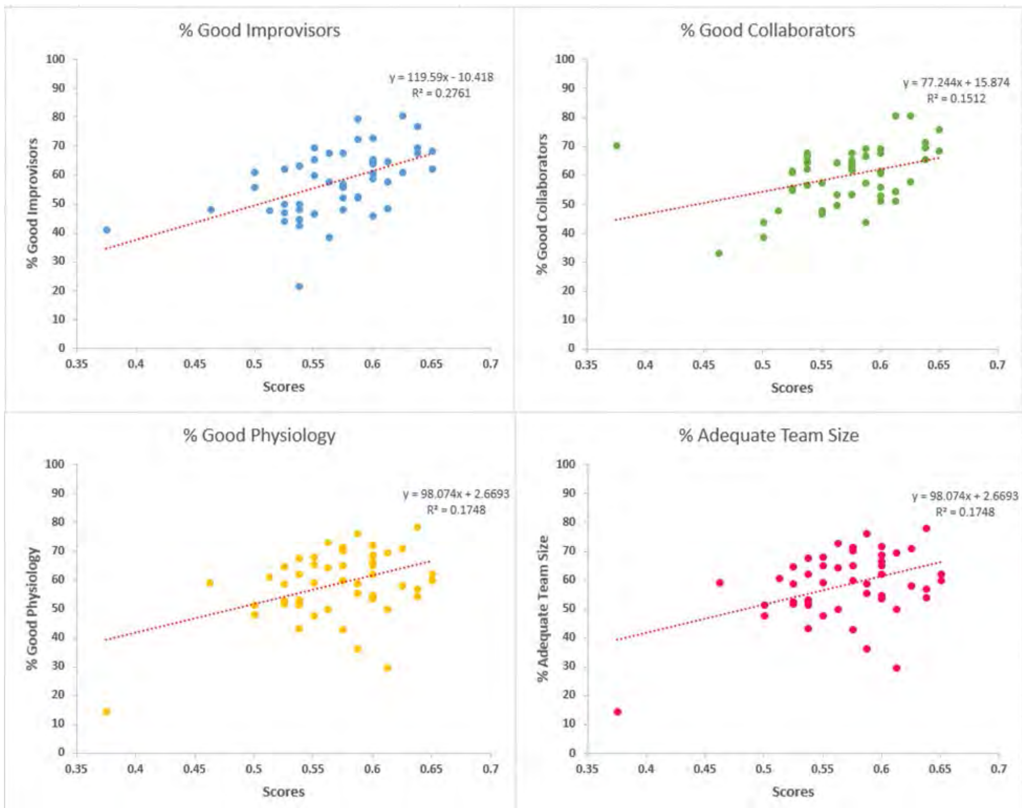

Figure 1: Scatter plot of % good improvisors, % good collaborators, % good physiology, and % adequate team size with scores.

6.1 Correlation Analysis

To gain deeper insights into the dynamics of team performance and project outcomes within the construction industry, correlation analysis was conducted on the data obtained from 100 simulation runs of the model. This analysis was aimed at exploring the relationships between team members' cognitive abilities, the adequacy of staffing, and the effectiveness of issue resolution strategies in influencing the overall project success. The results of the correlation analysis highlighted several key relationships that are instrumental in understanding how various factors contribute to project performance:

Regarding the relationships between scores and issue resolution, there is a strong positive correlation ($r = 0.67$) between the average scores and the number of resolved issues, suggesting that teams with higher performance scores are more effective in resolving project issues. Conversely, a significant negative correlation ($r = -0.51$) was observed between scores and the number of unresolved issues, indicating that higher scoring teams tend to leave fewer issues unresolved. As for cognitive abilities and team performance scores, a positive correlation ($r = 0.56$) between the percentage of good improvisors and the average scores highlights the importance of improvisation skills in achieving successful project outcomes. Similarly, the percentage of good collaborators shows a positive correlation ($r = 0.58$) with scores, emphasizing the role of collaboration in effective project management. The analysis also shows a positive correlation ($r = 0.57$) between the percentage of members with adequate physiological abilities and the project scores, highlighting the necessity of physical capabilities in handling construction tasks. For team size adequacy, there is a substantial positive correlation ($r = 0.62$) between the percentage of issues completed with enough workers and the average scores, confirming that adequately staffed teams are more likely to resolve issues effectively. Finally, regarding unsuccessful outcomes, there is a strong negative correlation between the percentage of unsuccessful issue resolutions and the average scores ($r = -0.87$). This highlights a critical insight: as the proportion of issues that are either unresolved or resolved with waste decreases, the overall performance scores increase, highlighting the detrimental impact of inadequate issue resolution on project outcomes. These correlations provide empirical support for the critical role of cognitive and physiological alignments in construction project management. By ensuring that team compositions are strategically aligned with the specific demands of the tasks at hand, project managers can substantially improve the likelihood of project success. This analysis not only validates the effectiveness of the model but also offers actionable insights that can be applied to enhance team management and project planning practices in the construction industry.

7 CONCLUSIONS

This paper has presented a detailed exploration of the role of cognitive diversity within construction project teams and its impact on project performance. Through the development and application of Agent-Based Modelling (ABM), a construction environment was simulated to assess how various cognitive abilities—specifically those related to improvisation, collaboration, and physiology—influence the resolution of project issues. The analysis of 100 simulation runs, divided evenly between random and optimal team assignments, has revealed significant findings. In the random assignment scenario, considerable variability in project outcomes was observed, highlighting the importance of each cognitive ability in achieving project goals. The optimal assignment strategy, in contrast, consistently produced superior results, highlighting the benefits of aligning team members' cognitive and physiological capabilities with task requirements.

The contributions of this research are multi-fold. It provides empirical evidence supporting the importance of strategic team composition in the construction industry. The ABM serves as a predictive tool that can be used to optimize team assembly and anticipate project performance, offering practical insights that can inform real-world construction management practices. However, some limitations exist. First, this study would benefit significantly from empirical validation, where predictions are tested against real-world outcomes. Sensitivity analysis can also be used to determine which cognitive traits most significantly impact outcomes. The reliance on simulated data, while valuable, does not capture the full complexity of human behavior and external variables that can affect project outcomes. Additionally, the ABM assumes that cognitive abilities can be accurately measured and translated into performance outcomes, which may not always reflect the nuanced realities of construction projects. For future research, it is recommended to extend the model to include additional cognitive abilities and human factors, which can significantly affect team dynamics. It is also suggested to conduct empirical studies to validate the model's predictions against actual project outcomes. Finally, it is essential to explore the impact of external factors such as economic conditions, technological advancements, and regulatory changes on project success. This paper advances the understanding of cognitive diversity in construction and introduces a novel approach to team assembly that could lead to more successful project outcomes.

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