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Green technological innovation, organizational resilience, and green intellectual capital: A study of SRDI SMEs

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Abstract

Unexpected changes have compelled business organizations to rapidly adapt to meet contemporary needs. One prevalent strategy is to incorporate technological innovation, which facilitates the implementation of adaptable management strategies and flexible working arrangements, enabling enterprises to adjust more effectively to dynamic market conditions and operational challenges. This study aims to understand the role of green technological innovation in enhancing the resilience of SRDI SMEs and explore how green intellectual capital supports SMEs in effectively responding to disruptive situations. This study contributes novel insights into the impact of green technological innovation and intellectual capital on SMEs' organizational resilience. Data were collected through a survey questionnaire administered to SRDI SMEs. The findings substantiate the significant positive relationship between green technological innovation and organizational resilience, mediated by green intellectual capital. This study suggests that SMEs should recognize their internal strengths and weaknesses regarding green technological innovation to integrate it effectively into their organizational operations. Small and Medium Enterprises (SMEs) can attain greater levels of digital maturity by integrating green intellectual capabilities and technological innovation, subsequently enhancing their resilience.

Keywords: Green technological innovation, Organizational resilience, Green intellectual capital, SRDI, SME

1. INTRODUCTION

The world is facing resource scarcity and environmental pollution in the pursuit of economic development. Achieving a balance between environmental preservation and economic growth is a challenge for sustainable development. Small and medium enterprises (SMEs) are a critical segment of the global economy, contributing to employment, innovation, and economic development. Their importance is more pronounced in developing countries, as SMEs represent over 90% of business activities, job creation, and a substantial share of GDP. In recent years, small and medium enterprises (SMEs) with "specialized, refined, differentiated, and innovative (SRDI)" characteristics have gained increasing research attention (Si et al., 2023) and are called "invisible champions". These invisible champions are the backbone for developed countries like Germany, with international market dominance and technology breakthrough initiatives. Among these invisible giants, SRDI in the manufacturing sector is most outstanding, and its development can optimize and upgrade the industrial structure in a developing country like South Korea. Furthermore, with growing interest in Asian market dynamics, scholars are exploring open innovation, disruptive innovation, and internationalization as key drivers of SME performance (Lee & Hemmert, 2023; Roh et al., 2023; Yu et al., 2023). Asian SRDI enterprises thrive in niche markets through innovation (Simon, 1992; Witt et al., 2024), and operating within global production systems and supplying specialized components to multinationals (Greeven et al., 2023). They grow through both imitation and innovation, positioning themselves as a competitive force in the digital age and reshaping global markets (Liu, 2024; Zahra et al., 2023)Additionally, the government emphasizes the need to support green technological innovation among SMEs, fostering SRDI SMEs in this domain. Therefore, an in-depth exploration of the behavior of SRDI enterprises towards green technological innovation can help formulate a model and guide for other SMEs.

The term twin transition has grabbed the attention of the academic and business communities in recent years. It refers to economic and social transformation that entails sustainability (the green transition) and adoption of technologies (the digitalization). The concept has garnered attention to address environmental challenges and to exploit the benefits of technologies for innovation and economic development (Ristanović et al., 2023). Sustainability transitions curb biodiversity loss and protect vital ecological services for healthy communities (Mace et al., 2018). Along with the sustainability shift, the digital transformation, driven by the increasing adoption of technologies, is closely associated and aligned (Llorente, 2024). Green technological innovation (GTI) combines green development and innovation-driven growth to improve carbon emission efficiency and promote industrial green transformation (Han, Xiao, & Dong, 2023). GTI is a more intelligent and promising transformation to achieve sustainability through making the world more efficient without harming the environment (Fouquet & Hippe, 2022). Technological shift is also a significant factor in improving the resilience to natural disasters and climate change, making it easier to achieve net-zero emissions and reducing emissions (Castro et al., 2021).

Organizational resilience is an important determinant of organizational success in an uncertain environment, with unforeseen crises, technological competition, and geopolitical shifts (Prayag, 2023). Barghouti et al. (2022) have considered resilience as a contextual factor, whereas Zhang et al. (2023) have termed it as a continuous capability formed and refined throughout the organizational development process. However, a consensus regarding a clear definition and meaning of resilience has not been developed. Some internal influencing factors of resilience at the individual level include leaders' behaviors, perceptions, and personal traits, and at the organizational level are the learning process, organizational resources, and organizational size (Jiao & Bu, 2024; Qiao et al., 2022). Whereas external factors include digital transformation, social responsibility, social capital, and policy environment (Gagalyuk & Kovalova, 2023; Sun et al., 2024; Yang & Deng, 2023). Zhang et al. (2023) emphasized the adoption of core technologies for survival. Studies have shown a positive impact of technological innovation on accelerating digitalization (Li et al., 2021), optimizing business models (Heredia et al., 2022), and promoting the industrial upgradation process (Ma et al., 2021).

Innovation is a knowledge-driven process that depends on the ability to develop, create, manage, and maintain human-generated knowledge (Schumpeter). Therefore, green intellectual capital, a combination of knowledge, skills of environmental issues, and interpersonal relationships within an organization, significantly influences the ability to adapt to environmental changes and remain resilient (Agostini & Nosella, 2023). While many researchers acknowledge the importance of green technology innovation in enhancing company resilience, few have investigated the impact of green intellectual capital investment alongside green technological innovation in this context.

The literature on the mediating effects of GIC in the relationship between GTI and organizational resilience is limited, leading to a significant gap in the literature that this study seeks to overcome. Furthermore, existing literature on intellectual capital, technological innovation, and organizational resilience is carried out under generalized business settings without explicitly considering the dynamics of SRDI SMEs. Therefore, it is imperative to investigate these relationships with the specific context of SRDI firms to develop a comprehensive understanding of the underlying dynamics of these business entities. Lastly, innovation and organizational resilience, green intellectual capital and innovation, and technological innovation and resilience have been explored in individual connections; however, the mechanism through which these factors are interconnected in terms of a mediation relationship remains unexplored. Therefore, the study aims to achieve the following objectives: examine the relationship between organizational green technological innovation, green intellectual capital, and resilience, check the impact of green technological innovation and green intellectual capital on organizational resilience, and explore the mediating role of green intellectual capital in the relationship between green technological innovation and organizational resilience.

2. THEORETICAL GROUNDING

Natural resource-based view (NRBV), theory of resilience (TOR), and theory of intellectual capital (TIC) provide the theoretical lens for the study. The natural resource-based view (NRBV) is the extension of RBV theory. NRBV implied that external conditions compel organizations to utilize resources and capacities to minimize their impact on the natural environment and turn threats into opportunities. By incorporating green technological initiatives and environment-friendly practices into business operations and promoting green human resources behaviors, organizations can have a competitive advantage over others (Makhloufi et al., 2022). Furthermore, efficient use of resources and capabilities enhances overall performance by specifically targeting the environmental and energy usage issues (Appannan et al., 2023). The framework of the theory of resilience enables us to investigate how technological innovation and GIC (human resources) can be effectively used to enhance organizational resilience. In addition, being concerned about sustainable practices enhances the perception and reputation of the organization, attracts customers who value environmental concerns, and fosters the competitive position (Yusliza et al., 2020). Thus, ICV facilitates the organizational commitments and processes to achieve goals and place organizations in competitive positions.

Organizational efforts to become digitally equipped, through technological innovation, and socially responsible (through green transformation), and investment in human capital to facilitate and ensure survival for long periods, the study has formulated the following hypotheses:

H1. Green technological innovation positively influences the resilience of SRDI enterprises

H2. Green technological innovation. positively influences the green intellectual capital of SRDI enterprises

H3. Green intellectual capital serves as a positive mediator in the relationship between green technological innovation and the resilience of SRDI enterprises

H3a. Green human capital serves as a positive mediator in the relationship between green technological innovation and the resilience of SRDI enterprises

H3b. Green structural capital serves as a positive mediator in the relationship between green technological innovation and the resilience of SRDI enterprises

H3c. Green relational capital serves as a positive mediator in the relationship between green technological innovation and the resilience of SRDI enterprises

The research model diagram of this paper is shown in Figure 1.

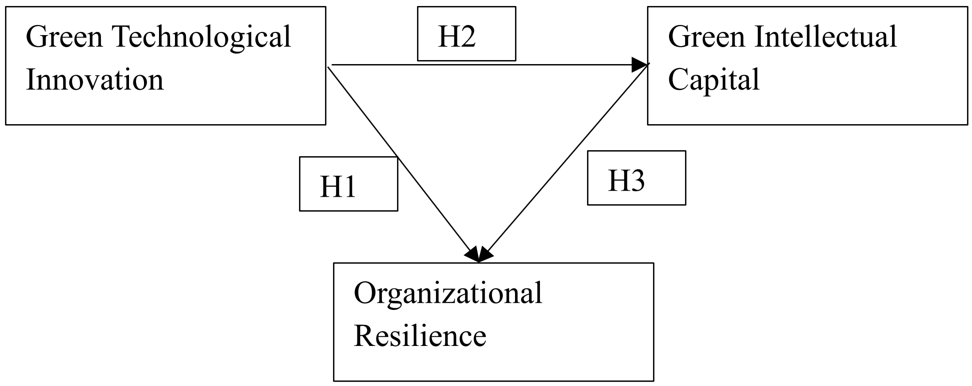

Figure1. Conceptual Model

3. METHODOLOGY

3.1. Data collection:

Organizations are the unit of analysis for the current study to test the hypothesis. We used the dataset of Korean innovative business enterprises (called Inno-Biz). These are highly innovative enterprises certified by the Korean Ministry of SMEs and Startups. Initial information about the innovative initiatives of these enterprises is collected from the KIS (Korean Innovation Survey) database organized by STEPI (Science and Technology Policy Institute) for manufacturing firms. The database contains financial and demographic information, along with the innovation activities of these enterprises. Keeping in mind the objectives of the study, we selected the sample of firms based on two criteria in line with the study of Roh et al. (2023). First, the sample is restricted to Inno-Biz SMEs (characterized as SDRI) as they are likely to engage and value innovative activities because, for survival, they need to be more innovative. Second, the study is restricted to manufacturing Inno-Biz enterprises as service firms have different parameters to improve performance based on innovative activities. Thus, these criteria enable us to better understand and address the important aspects of green technological innovation and intellectual capital and explain their role in improving enterprises' resilience. The data was collected from all employees working in these SRDIs, irrespective of the managerial level in the organization. Although the study's unit of analysis is organizations, survey data were collected from individual employees. Therefore, responses from multiple employees within the same enterprise were aggregated to represent organizational-level constructs. Interrater agreement and reliability were assessed using standard measures such as RWG (within-group agreement index) and ICC (intraclass correlation coefficient) to justify this aggregation. Satisfactory values (RWG > 0.50, ICC(1) > 0.05) confirmed sufficient agreement among respondents, supporting the validity of aggregation.

3.2. Variables and measurements:

A quantitative research method is applied in the study to examine the relationship between green technological innovation, green

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intellectual capital, and organizational resilience. The questionnaire consists of two parts. The first is related to the demographic information of respondents. This includes age, education level, and gender, and the second part is about specific scale items of the questionnaire. The items are related to three primary constructs of the study: green technological innovation, green intellectual capital, and organizational resilience. All the multi-item variables are measured using a five-point Likert scale ranging from strongly disagree to strongly agree. To ensure the reliability and validity of the questionnaire, the measures are taken from established scales used in the literature and changed according to the characteristics of SRDI manufacturing enterprises.

Organizational resilience is measured with the 6 components derived from the literature (Blatz et al., 2018; Siebert & Gaskin, 2006; Sila, 2007; Wided, 2023; Xia & Delei, 2024). The measures of green intellectual capital are taken from the study of Hina et al. (2024). The measures of green technological innovation are derived from 10 items from the literature (Cao et al., 2025; Wu & Tham, 2023). Control variables have been used in the study to rule out alternative explanations for SRDI enterprises' innovation capability and resilience performance. In line with the prior studies (Bhatti et al., 2024; Chatterji et al., 2019), firm age has been included in the study to proxy the general knowledge of enterprises. Second, as the analysis comprises various industries from the manufacturing sector of Inno-Biz enterprises, the industry effect has been controlled. Third, the size of the enterprises may influence the analysis of firms, which is also controlled in the study. Gender, age, and education level of respondents have also been used as controlled variables in the current study.

3.3. Data Description:

The data consists of employees' responses to evaluate the measures taken by their organization to employ green technology and investment in improving green intellectual capital, which ultimately are helpful to improve enterprises' resilience level. There are three exogenous constructs: green human capital (GHC), green relational capital (GRC), and green structural capital (GSC). These are first-order constructs and composite green intellectual capital (GIC) dimensions. Green intellectual capital has been used in the study as a formative construct (second-order construct), whereas dependent and independent variables are reflective constructs. The conceptual model is shown in Figure 2.

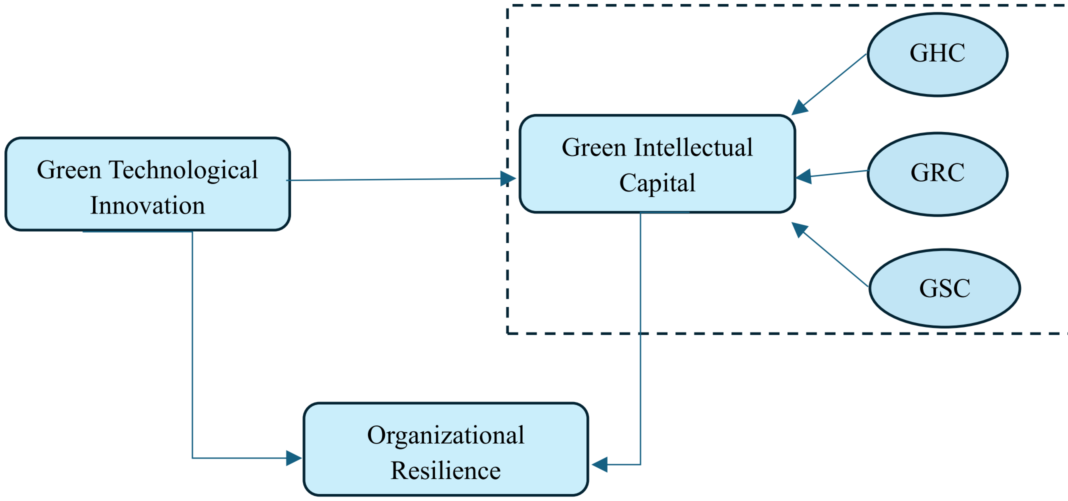


Figure 2: Formative-Reflective Model

Table 1 consists of demographic data of survey participants. Three hundred thirty-six employees from various enterprises participated in the survey. Of these respondents, 71% were male and 29% were female. Most respondents are between 31 and 45 years (37.2%), between 20 and 30 years are 29.46%, between 46 and 60 years are 19.04%, and 14.29% are above 60 years. From an educational perspective, most employees have completed a bachelor's degree (52.97%). From an experience perspective, most employees who participated in the survey have 6-9 years of experience.

Table 1. Demographic profile.

	Description	Frequency	Percentage
Gender	Male	239	70.90%
	Female	98	29.10%
Age	20–30 Years old	99	29.46%
	31–45 Years old	125	37.20%
	46–60 Years old	64	19.04%
	>60 Years old	48	14.29%
Experience	1–2 Years old	67	19.95%
	3–5 Years old	88	26.19%
	6-9 Years old	105	31.25%
	> 10 Years old	76	22.62%
Education	High School/Similar	86	25.59%
	Diploma	17	5.06%
	Bachelor's degree	178	52.97%
	Master's degree and above	55	16.34%
Industry Type	Clothing and textiles manufacturing	36	10.80%

Petroleum, chemicals, and plastics	61	18.20%
Cement	65	19.20%
Wood, leather, and paper	75	22.40%
Pharmaceuticals	43	12.80%
Food Production	56	16.60%

Common Method Bias: The data is collected through a survey questionnaire; therefore, a standard method bias problem is probable. CMB may weaken the study results and exaggerate the relationship between variables (Spector, 2006). Harman's single-factor model was applied to confirm that the study is free from CMB issues. The results of the test revealed that the value of HSF is less than 50%, which meets the threshold limit of the test (Hair Jr et al., 2021). Furthermore, the full collinearity test is also checked for consistent results. VIF values should be less than the cut-off value of 3.3 (Kock, 2015). The results below confirm that the VIF values are less than the threshold limit, which also rules out the possibility of CMB.

3.4. Measurement Model:

In the first step of analysis, the reliability and validity of the lower-order reflective constructs are confirmed. In line with Hair Jr et al. (2021) study, reliability is measured through composite reliability measures and Cronbach's alpha value. Table 2 provides the values of Cronbach's alpha, which lie between 0.833 and 0.908 and surpass the threshold limit of 0.70. Composite reliability values are above the threshold level of 0.80. Both values confirm the high internal consistency. Moreover, Hair Jr et al. (2021) recommended that the average variance extracted (AVE) of constructs should be more than 0.5 to establish convergent validity. Table 2 confirms the value of convergent validity, and the reported values are above 0.5. To deal with the multicollinearity issue, the value of VIF should not be more than 3.3 (Hair Jr et al., 2021). Table 2 shows that the values are in range and confirms the absence of a multicollinearity issue.

Table 2. Validity and reliability of the reflective model (phase 1)

Variables		Factor Loadings	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)	VIF
GHC			0.908	0.909	0.935	0.783	2.11
	GHC1	0.892					3.199
	GHC2	0.903					3.301
	GHC3	0.896					2.962
	GHC4	0.848					2.345
GRC			0.892	0.893	0.933	0.823	1.96
	GRC1	0.898					2.795

	GRC2	0.905					2.849
	GRC3	0.918					3.022
GSC			0.901	0.902	0.927	0.716	2.54
	GSC1	0.853					3.163
	GSC2	0.878					3.643
	GSC3	0.826					2.564
	GSC4	0.830					2.629
	GSC5	0.844					2.422
GTI			0.835	0.855	0.882	0.601	1.59
	GTI1	0.855					2.236
	GTI2	0.734					1.892
	GTI3	0.762					1.882
	GTI4	0.697					2.185
	GTI5	0.816					2.184
OR			0.833	0.848	0.889	0.669	1.548
	OR1	0.807					1.732
	OR2	0.710					1.519
	OR3	0.894					2.677
	OR4	0.850					2.258

Discriminant validity can be explained with three criteria: the first is through cross-loadings. Hair Jr et al. (2021) suggested that each item loading should be greater than 0.5 and it should also be above the cross loadings. Table 3 provides the values of cross-loadings that confirm the constructs' criterion and validity. Second, in social sciences, Fornell and Larcker (1981) devised a criterion that is mainly used to determine the discriminant validity. This criterion compares the square root value of AVE with correlations between constructs. AVE square root value should be greater than the respective inter-construct correlations. Table 3 shows that all AVE values are above 0.5, which confirms the threshold limit and validity. The third and last technique to determine the discriminant validity is the Heterotrait-Monotrait ratio of correlations (HTMT) suggested by Henseler et al. (2015). The maximum range of the HTMT ratio is 0- 0.85. Table 3 indicates that all correlation values are below 0.85; therefore, there is no problem of discriminant validity.

Table 3. Discriminant Validity

Fornell-Larcker criterion

	GHC	GRC	GSC	GTI	OR
GHC	**0.885**				
GRC	0.600	**0.907**			
GSC	0.699	0.648	**0.846**		
GTI	0.467	0.524	0.572	**0.775**	

OR	0.719	0.670	0.731	0.686	**0.818**

Loadings and Cross Loadings

	GHC	GRC	GSC	GTI	OR
GHC1	**0.892**	0.547	0.620	0.423	0.659
GHC2	**0.903**	0.516	0.654	0.410	0.684
GHC3	**0.896**	0.535	0.630	0.437	0.631
GHC4	**0.848**	0.526	0.567	0.382	0.567
GRC1	0.596	**0.898**	0.621	0.456	0.630
GRC2	0.515	**0.905**	0.567	0.494	0.602
GRC3	0.517	**0.918**	0.573	0.477	0.589
GSC1	0.626	0.537	**0.853**	0.449	0.632
GSC2	0.640	0.569	**0.878**	0.450	0.633
GSC3	0.556	0.516	**0.826**	0.503	0.588
GSC4	0.580	0.561	**0.830**	0.553	0.635
GSC5	0.551	0.560	**0.844**	0.471	0.604
GTI1	0.435	0.451	0.522	**0.855**	0.677
GTI2`	0.416	0.418	0.509	**0.734**	0.573
GTI3	0.283	0.433	0.344	**0.762**	0.425
GTI4	0.268	0.258	0.332	**0.697**	0.357
GTI5	0.358	0.435	0.452	**0.816**	0.539
OR1	0.546	0.554	0.614	0.561	**0.807**
OR2	0.379	0.400	0.453	0.565	**0.710**
OR3	0.650	0.636	0.660	0.584	**0.894**
OR4	0.731	0.576	0.640	0.548	**0.850**

Heterotrait-monotrait ratio (HTMT) - Matrix

	GHC	GRC	GSC	GTI	OR
GHC					
GRC	0.665				
GSC	0.771	0.722			
GTI	0.520	0.596	0.642		
OR	0.812	0.768	0.837	0.799	

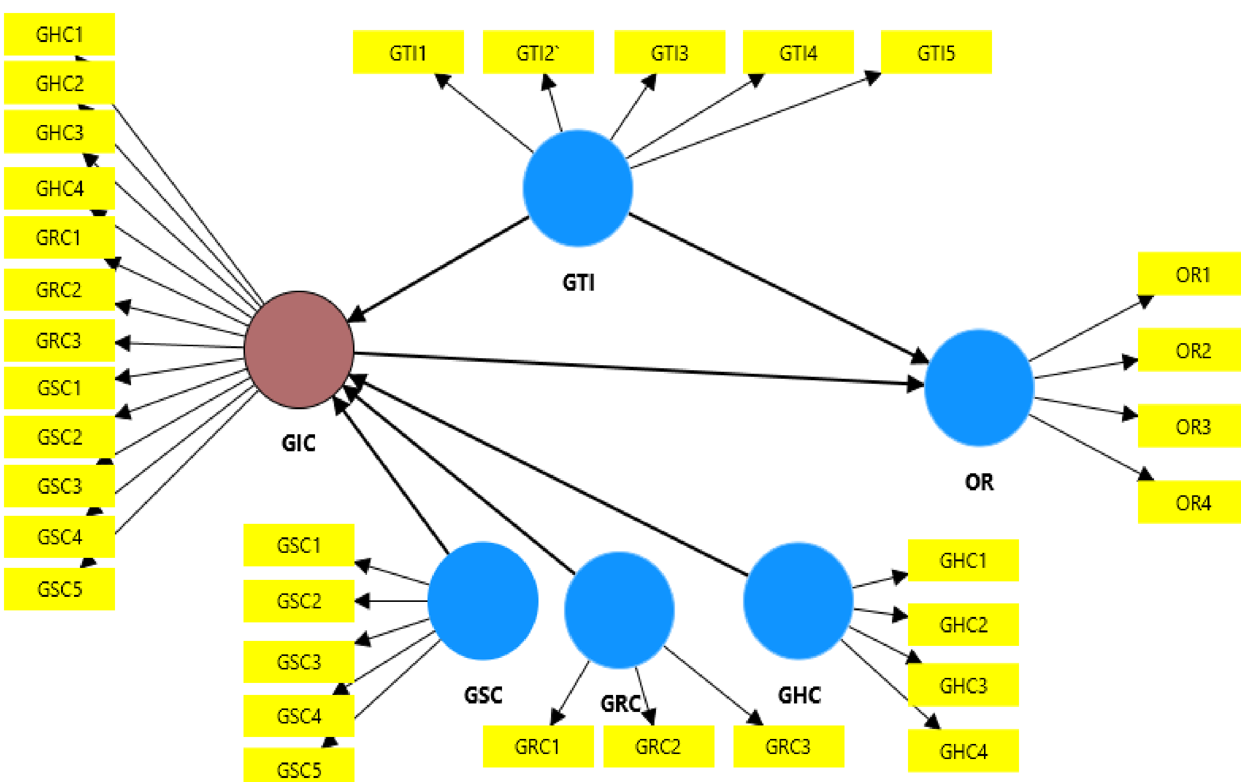
4. MEASUREMENT MODEL WITH FINDINGS.

In the second phase of analysis, the first phase's construct scores are used as formative assessment indicators. The convergent validity of higher-order constructs is confirmed by the reflective formative higher-order model proposed by (Hair Jr et al., 2021)The VIF values of lower-order constructs are below the threshold limit of 3.3, as presented in Table 4. Therefore, this confirms the absence of collinearity issues. Moreover, the outer weights of all formative indicators are statistically significant. The structural model was assessed by meeting all the criteria for higher-order construct validity.

5. Table 3. Higher-order construct validity (phase 2).

Higher-order construct	**Indicators**	**Significance and relevance of outer weights**				**Collinearity**
		Weights	**t-value**	**Loadings**	**t-value**	**VIF**
Green Intellectual Capital	GHC	0.301	4.082	0.85	23.181	2.107
	GRC	0.351	4.964	0.846	22.301	1.860
	GSC	0.485	6.455	0.923	44.402	2.327

Figure 3. Reflective lower-order constructs model



4.1. Structural model assessment:

The structural model confirms the causal relationship between dependent and independent variables (Hair Jr et al., 2021). Table 4 shows the assessment of the structural model. To evaluate the structural model, path coefficients (β β-values), coefficient of determination (R2), and effect size (f^2) values are assessed. R^2 is used for the variance portion of model accuracy. The results indicate that the model can explain 36% of the variation in green intellectual capital and 71% in organizational resilience. Moreover, the effect size known as f^2 can also be used to determine the significant effect of the independent variable on the dependent variable. The ranges of effect size are as follows: if the f^2 value is greater than or equal to 0.02, the effect is weak; if the value is greater than or equal to 0.15, it shows a moderate effect, and a value greater than or equal to 0.35 shows a large effect size. The results reported in Table 4 show that GTI has a large effect size on GIC (0.568) and a moderate effect on OR (0.221), whereas GIC has a strong effect on OR (0.841). Furthermore, by analyzing the structural model effects in Table 4, we found that all remaining relationships are statistically significant based on 95% bias-corrected bootstrap confidence-interval values. For the significant relationships, we found that GTI has significant effects on OR, and green intellectual capital has a positive and significant mediating relationship.

Figure 4. Formative model

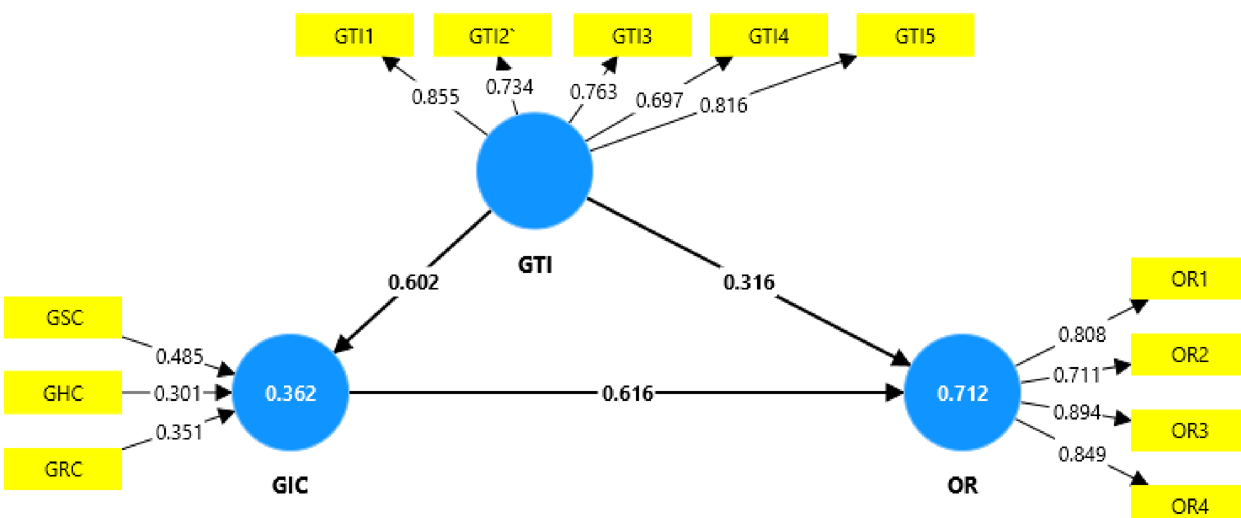


Table 4. Structural model assessment.

	Beta	CI-Min	CI-Max	t values	P values	f2	R2	Decision
GTI -> GIC	0.602	0.509	0.667	15.077	0.000	0.568	0.360	Supported
GIC -> OR	0.616	0.535	0.687	16.040	0.000	0.841		Supported
GTI -> OR	0.316	0.237	0.395	7.929	0.000	0.221	0.711	Supported

Mediation Analysis

GTI -> GIC -> OR	0.370	0.306	0.428	11.739	0.000	Supported

Most researchers utilizing the PLS-SEM and regression-based methods in the literature have overlooked evaluating the overall model's predictability beyond observed data. Most of the models are based on and explain the R^2 measures, which solely reflect the model's explanatory power, and do not provide an indication of the effectiveness of the model in predicting outcomes beyond the observed data (Chin et al., 2020). Thus, we followed the following steps to validate the explanatory power of the sample. Ringle et al. (2023) and conducted out-of-sample predictive relevance via $PLS_{predict}$ (Shmueli et al., 2019). The findings are presented in Table 5 below. The results indicate that $Q^2_{predict}$ values are greater than zero, which indicates the model's ability to predict outcomes beyond the observed data. In addition to this, the RMSE values of the PLS-SEM and linear regression (LM) models are compared. Some of the values of RMSE-PLS are high, and some of the values are lower than RMSE-LM values, which suggests a mixed pattern of predictive power in endogenous constructs (Hair et al., 2019).

Table 5. PLSpredict

	Q²predict	**PLS-SEM_RMSE**	**LM_RMSE**	**Difference RMSE**	**PLS-SEM_MAE**	**LM_MAE**	**Difference MAE**
GHC	0.207	0.894	0.900	**-0.006**	0.685	0.692	**-0.008**
GRC	0.268	0.858	0.858	0.000	0.656	0.656	0.000
GSC	0.317	0.830	0.831	**-0.001**	0.639	0.635	0.004
OR1	0.308	1.023	1.011	0.012	0.768	0.747	0.021
OR2	0.308	1.084	1.035	0.049	0.792	0.732	0.060
OR3	0.333	1.124	1.118	0.006	0.824	0.807	0.017
OR4	0.292	1.182	1.188	**-0.007**	0.904	0.913	**-0.009**

6. Discussion and Conclusion:

The study has provided significant insights into the relationship between green technological innovation (GTI), green intellectual capital (GIC), and organizational resilience (OR). The results indicate that GTI has positive and significant effects on ($\beta = 0.602$, $t = 15.077$, $p < 0.001$, $f^2 = 0.568$). It suggests that SRDI enterprises investing in green technological innovations have stronger, eco-friendly innovation capabilities. This result supports the role of technological advancements in enhancing innovation potential.

In addition to this, green intellectual capital (GIC) has also positive and significant effects on organizational resilience ($\beta = 0.616$, $t = 16.040$, $p < 0.001$, $f^2 = 0.841$). It confirms that SRDI enterprises with strong green innovation capabilities are more resilient than others. These findings emphasize and support the importance of adopting green innovation strategies to improve sustainability and adaptability in disruptive environments.

GTI also directly affects organizational resilience ($\beta = 0.316$, $t = 7.929$, $p < 0.001$, $f^2 = 0.221$), but the effect is more negligible compared to the indirect path through GIC. The mediation results have also supported this, where GIC significantly and positively mediates the relationship between GTI and OR ($\beta = 0.370$, $t = 11.739$, $p < 0.001$). This implies that although technological innovation contributes to resilience, this effect is amplified through the development of innovation capabilities. From the perspective of explanatory power of the model, the R^2 values indicate substantial predictive power. GIC explains 36.0% of the variance in OR, while GTI and GIC together explain 71.1% of the variance in OR. These results reinforce the importance of both direct and indirect pathways in fostering organizational resilience through innovation.

This study highlights the important and critical role of green technological innovation (GTI) and green intellectual capital (GIC) in driving organizational resilience (OR). The results confirmed that GIC is a potent mediator, and SRDI enterprises must focus on developing intellectual capital to get the maximum benefits of technological advancements. The study's practical implications suggest that enterprises should invest in green technologies and strengthen their intellectual capital to enhance resilience. Policymakers and business leaders should emphasize the integration of sustainability and innovation strategies, ensuring competitive advantages. Future research could explore additional moderating factors (e.g., industry type, firm size, and regulatory environment) to understand further how different organizational contexts shape these relationships. Expanding the study across different regions and industries would provide deeper insights into the broader applicability of green innovation strategies in enhancing resilience.

6. Implications of the study: The study has the following contributions:

Theoretical & Practical Implications: Considering the unique characteristics of SRDI SMEs, this study focuses on developing and enhancing the resilience of SRDIs. It explores the operational mechanisms of green intellectual capital and green technological innovation on enterprise resilience, while offering management suggestions for implementation. The study illustrates how SRDI enterprises can adjust their strategies to maintain resilience under disruptive conditions. It broadens the resilience framework of SRDI SMEs by integrating GIC and GTI. Furthermore, it emphasizes the mediating role of GIC and provides new insights on how GIC connects GTI to resilience within the existing literature. Additionally, it clarifies the mechanisms of selected variables in the context of SRDI enterprises, extending the current knowledge base.

Policy Implications: By fostering GTI and leveraging GIC, SRDI enterprises can enhance resource efficiency, reduce environmental impact, and improve sustainability, thus achieving both economic resilience and ecological benefits. SRDI enterprises can quickly adjust their strategies, minimize pollution, optimize resources, and proactively respond to environmental challenges amidst uncertainties such as economic cycles, pandemics, market fluctuations, and natural disasters. SRDIs can create a win-win situation through environmental protection and societal development.

7. Limitations and Future Research Directions:

The study has several limitations. First, manufacturing SRDI enterprises was the focus of the study. Although the approach was justified for this study, the service sector could also provide insightful information and an in-depth understanding of the mechanisms and strategies they adopted. Second, a comparative study of the manufacturing and service sectors can also help make comparisons of approaches in both sectors and provide an in-depth understanding of how leaders in both sectors are targeting sustainability. Third, the study sample may be gender biased as there are more male than female respondents. This ratio can be improved if data is collected from other sectors and regions. Finally, the study particularly focuses on SRDI SMEs of South Korea, which has a unique cultural, institutional, and regulatory context; therefore, caution should be taken while generalizing the results.

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