Evaluation of Technologies Ensuring Green Performance in Multi-family Housing Projects in Korea

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Abstract
Because the energy consumption of the Korean construction industry accounts for 18.8% of Korea's entire energy consumption, the construction industry has considered a variety of techniques for enabling energy savings on construction projects. In particular, the construction of multi-family housing projects in Korea is one of the key areas where efforts can be made to reduce energy consumption. Consequently, many Korean construction companies are investing considerable effort toward developing advanced green performance techniques, including heating, cooling and electricity. This study identified the various techniques available to achieve green performance in multi-family housing projects, and surveyed the expert's perceptions of the techniques identified to suggest established, emerging, and opportunity green techniques to the Korean construction industry. This paper is expected to provide guidelines for developing technologies that can successfully deliver future energy-efficient multi-family housing projects in Korea.

Keywords: green techniques; ISA method; multi-family housing projects; construction industry

1. Introduction
1.1 Research Background and Objectives
After the Kyoto Protocol for reducing greenhouse gas emissions was adopted a few years ago, many governments in industrialized countries around the world have been working on more environmentally-friendly energy sources (Chung and Rhee, 2013). The Korean government has mandated that all industries in their country undertake efforts to accomplish reductions in both their environmental pollution emissions as well as their fossil-based energy consumption. With the construction industry, which consumes 18.8% of Korea's total consumption, a range of energy-saving techniques on construction projects are being considered (Jin and Kim, 2013). In particular, multi-family housing projects in Korea are one of the key areas identified for energy savings owing to their heavy energy consumption, and many Korean construction companies are focusing their efforts in this area by developing advanced techniques in terms of green performance, including heating, cooling and electricity. Some of these techniques, however, are in the early stages of development, and the Korean construction industry has only recently begun to undertake such efforts. Consequently, this is a new area for project owners, engineers, and designers to both select and apply particular techniques to their projects in accordance with the requirements of the Korean government.

For the successful delivery of eco-friendly multi-family housing projects in Korea, it would be extremely helpful to explore the existing techniques developed by several construction companies, as well as assess the perception of them by experts with respect to their green performance. In this context, the aim of this study was to identify not only the influence of existing techniques in achieving green performance, but also the satisfaction level of experts with them at their current stage of technical maturity. Moreover, along with the measured results in terms of their influence and satisfaction levels, this study identifies the established, emerging, and opportunity techniques among the various green techniques, which can be used as a tool for project owners, engineers, and designers in adopting particular techniques into their projects.

1.2 Research Methodology
This study was conducted based on three steps. In Step 1, the current construction techniques that improve the green performance for multi-family housing projects were explored by a thorough literature review and interviews with several experts in the construction industry. As a result, this study identified 77 techniques that are being developed and/or are being adopted in the construction industry. In Step 2, a questionnaire was conducted to measure the perception...
of respondents to 77 techniques in terms of their influence and satisfaction with the identified techniques in achieving the required green performance. The results of the survey were used to conduct an Importance Satisfaction Analysis (ISA), which allowed identification of the techniques that were perceived to be effective in the construction industry in accordance with the required green performance. In Step 3, the ISA results were explored to assist not only the construction project participants in selecting particular techniques for their projects, but also researchers in the Korean construction industry to develop a direction for future research to improve green performance.

Table 1. Techniques Using Renewable Energy

| Photovoltaic techniques                  | 1-A1 | BIPV system installed to façade |
|------------------------------------------|------|---------------------------------|
|                                          | 1-A2 | BIPV system installed to guardrail |
|                                          | 1-A3 | BIPV system installed to roof    |
|                                          | 1-A4 | BIPV system installed to awning  |
|                                          | 1-A5 | BIPV system integrated with roof planting system |
|                                          | 1-A6 | Lights powered by PV             |
|                                          | 1-A7 | Charging system for vehicle using PV |
|                                          | 1-A8 | Glass block using PV             |
|                                          | 1-A9 | DSSC (Dye-Sensitized Solar Cell) |
| Geothermal techniques                   | 1-B1 | Heating system using geothermal heat |
|                                          | 1-B2 | Coil for gathering geothermal heat |
|                                          | 1-B3 | Cooling system using rainwater   |
|                                          | 1-B4 | Heat pump                        |
|                                          | 1-B5 | Low energy - floor heating system |
|                                          | 1-B6 | Geothermal heat based snow melting system |
|                                          | 1-B7 | Cool tube system using geothermal heat |
| Wind power used techniques              | 1-C1 | Wind power generation system     |
|                                          | 1-C2 | Building integrated wind power generation system |
|                                          | 1-C3 | Lights powered by wind power generation system |

2. Green Techniques in Multi-family Housing Construction Projects

From a thorough literature review and interviews with experts from leading construction companies in Korea, 77 techniques pursuing green performance on multi-family housing projects were identified. Tables 1. to 4. show the categorized techniques, which include renewable energy, natural resources, and green materials. As shown in Table 1., 19 techniques were extracted from the field of techniques using renewable energy (i.e. photovoltaics, geothermal energy, and wind power). For example, for techniques using photovoltaic energy, five types of Building Integrated PhotoVoltaic (BIPV) Systems are shown according to the building location of the installation. In addition, there are four techniques shown using photovoltaic energy (1-A6, 1-A7, 1-A8, and 1-A9) that can reduce the electricity consumption of a house. Please refer to Table 1. for more information on the techniques using geothermal energy and wind energy.

As shown in Table 2., 13 techniques using natural resources were found; six techniques reuse and recycle rainwater and used water, and seven techniques incorporate natural air and lighting into the buildings. Moreover, construction companies in Korea have developed techniques for improving the thermal insulation performance and residential performance of houses using a range of green materials, as shown in Table 3. Twenty techniques were examined; see Table 3. for more information.

Table 2. Techniques Using Natural Resources

| Techniques regarding water recycling          | 2-A1 | Total system for water recycling |
|                                             | 2-A2 | System using rainwater           |
|                                             | 2-A3 | Eco-friendly waste water recycle system |
|                                             | 2-A4 | Rainwater permeating pavement blocks |
|                                             | 2-A5 | Rainwater recycled gardening water |
|                                             | 2-A6 | Rainwater used air conditioning system |
| Eco-friendly design techniques              | 2-B1 | Roof garden system               |
|                                             | 2-B2 | Natural lighting system          |
|                                             | 2-B3 | Natural ventilation system       |
|                                             | 2-B4 | Natural air conditioning system  |
|                                             | 2-B5 | Eco-friendly water space         |
|                                             | 2-B6 | Flexible floor plan              |
|                                             | 2-B7 | Rahmen system                    |

Moreover, construction companies in Korea have developed techniques for improving the thermal insulation performance and residential performance of houses using a range of green materials, as shown in Table 3. Twenty techniques were examined; see Table 3. for more information.

Table 3. Techniques Related to Green Materials

| Thermal insulation techniques               | 3-A1 | Super thermal insulation materials |
|                                          | 3-A2 | Glass-wool inserted insulation material |
|                                          | 3-A3 | Mineral wool inserted - half drying insulation |
|                                          | 3-A4 | Mineral wool inserted - drying insulation |
| Materials for finish works                | 3-B1 | Finishing materials controlling humidity |
|                                          | 3-B2 | Finishing materials incorporating bio-tech. |
|                                          | 3-B3 | Materials reducing harmful substances |
|                                          | 3-B4 | Mineral paint |
|                                          | 3-B5 | Healthy wallpaper |
|                                          | 3-B6 | Eco-friendly glues |
|                                          | 3-B7 | Eco-friendly flooring materials |
| Other materials                           | 3-C1 | Radiant heat panel on ceiling |
|                                          | 3-C2 | Storage sheet accumulating latent heat |
|                                          | 3-C3 | Recycled wood |
|                                          | 3-C4 | Synthetic wood |
|                                          | 3-C5 | Glass block made by recycled glass |
|                                          | 3-C6 | Eco-friendly mortar |
|                                          | 3-C7 | Eco-friendly concrete |
|                                          | 3-C8 | High functioning gypsum board |
|                                          | 3-C9 | PCM gypsum board |

As shown in Table 4., 25 techniques that reduce home energy consumption were identified. The techniques focused on developing high-performance products for the house, such as windows and doors, bathroom fixtures, and electrical installations and products.

3. Importance Satisfactory Analysis (ISA)

ISA is generally applied to various research fields, where a structure is needed to determine how the respondents perceive particular research problems, using the survey results regarding the importance and satisfaction. According to Hair et al. (2010), ISA offers two distinct advantages to other research methodologies for measuring the magnitude of various research problems. First, it allows a researcher to
assess the respondents' perceptions of certain research problems. Second, ISA offers advantages over other interdependence techniques, such as cluster analysis, in that ISA does not rely on the establishment of a variate, as required in various regression techniques (Wright, 2012). Therefore, this research selected the ISA method to identify (i) how construction engineers perceive the 77 techniques in terms of the technique's "influence level" to acquire green performance for houses and the "satisfaction level" with the current technical maturity of the techniques, and (ii) what techniques can be considered opportunity techniques, emerging techniques, and established green techniques according to their relative influence and satisfaction levels.

The interpretation of the relative perception of the influence (i.e. importance) and satisfaction with each technique when adapted to multi-family housing projects required the development of a perceptual map, which is also known as an action grid, as shown in Fig.1. The action grid for this research was developed using the dimensions of influence on the vertical axis and the satisfaction on the horizontal axis. The four quadrants of the action grid were determined using the mean response values for the responses of all the technologies in the survey (Martilla and James, 1977).

As shown in Fig.1., the results of the ISA action grid can be interpreted directly. The four quadrants are determined using the mean-of-means value for both dimensions. Quadrant I (Concentrate Here) indicates the technologies with high influence and low relative satisfaction in achieving green performance. The technologies falling into this quadrant are the technologies requiring the greatest emphasis to meet industry requirements. Quadrant II (Keep up the Good Work) identifies technologies of high influence and high satisfaction. These technologies require a sustained level of influence on green performance, but are already achieving a high level of industry satisfaction. Quadrant III (Low Priority) represents the technologies with low influence on the green performance and low satisfaction. Quadrant IV (Possibly Too Much) represents the technologies with low influence and high industry satisfaction. Quadrants III and IV warrant the least emphasis because they are the least important technologies to the industry.

Further, as shown in Fig.1., this study attempted to classify the techniques as either opportunity, emerging, or established construction technologies based on the definitions presented earlier in this paper. The rationale for determining opportunity, emerging, and established green technologies follows the following rubric (Wright, 2012): Opportunity Technologies shall be considered as those technologies whose influence has been measured to be in excess of one standard deviation above the mean-of-means and whose satisfaction has been measured to be less than one standard deviation below the mean-of-means (please refer to Eq. 1 and area " □ " in Fig.1.).

\[
\text{if } \forall i \in \text{Oppor.Tech.}, \text{ then } + \sigma < M_I, \text{ and } M_S \leq -\sigma \quad \cdots (1)
\]

where \( i \) = a random technology, \( M_I \) = Mean of Influence values for \( i \), \( M_S \) = Mean of Satisfaction values for \( i \), and \( \sigma \) = standard deviation of the mean-of-means

Emerging technologies shall be considered as those technologies whose influence is within one standard deviation of the mean-of-means and whose satisfaction has been measured to be less than one standard deviation below the mean-of-means (please refer to Eq. 2 and area " □ " in Fig.1.).

\[
\text{if } \forall i \in \text{Emerg.Tech.}, \text{ then } -\sigma \leq M_I \leq +\sigma \text{ and } M_S \leq +\sigma \quad \cdots (2)
\]

Established technologies shall be considered as those technologies whose influence has been measured to be greater than one standard deviation below the mean-of-means and whose satisfaction is in excess of one standard deviation above the mean-of-means.

Table 4. Techniques for Reducing Energy Consumption

| Windows and doors                  |
|------------------------------------|
| 4-A1 Triple glass                  |
| 4-A2 Triple glass adding one-sided Low-E glass |
| 4-A3 Triple glass adding double-sided Low-E glass |
| 4-A4 Air-tight doors               |
| 4-A5 Double skin façade system     |
| 4-A6 High efficiency polymer filter|
| 4-A7 Eco-friendly DNA filter       |
| 4-A8 Balcony system adding thermal insulation |

| Bathroom products                  |
|------------------------------------|
| 5-A1 Smart bath system             |
| 5-A2 Waterless urinal              |
| 5-A3 Sense-based water saving faucet|
| 5-A4 Water-saving toilet bowl      |

| Electrical installations          |
|------------------------------------|
| 6-A1 Fuel cell for emergency      |
| 6-A2 Techniques protecting electricity loss |
| 6-A3 Shut off-systems of standby power|
| 6-A4 LED lights                   |
| 6-A5 Light control system saving electricity |
| 6-A6 Smart ventilation system     |
| 6-A7 Energy saving – duct         |
| 6-A8 Valves for saving heating energy |
| 6-A9 Heat recovery ventilator     |
| 6-A10 Indoor environment control system |
| 6-A11 Bedroom environment control system |
| 6-A12 Energy monitoring system    |
| 6-A13 Home smart grid             |

Fig.1. Modified ISA Method from Wright 2012
Influence measurement in Fig.1).

All other technologies not described in the rubric will be considered low priority in achieving green performance in multi-family housing projects.

4. Data Collection

This study conducted a questionnaire survey, the data from which was used in the ISA procedure.

4.1 Survey Design

The survey was designed to measure the respondents' professional judgment of the level of influence of particular techniques on the successful delivery of multi-family housing projects with significant green performance. A separate series of questions that asked respondents to rate their professional satisfaction with the techniques in terms of the current technical maturity was also posed. All questions were based on a likert scale from zero to five, with zero representing no influence/not satisfied and five representing most important/completely satisfied. Data collection was conducted from July to August 2012 by sending the potential respondents an initial e-mail invitation and one e-mail reminder thereafter, requesting their responses to the questionnaire survey.

Because the research objective was to identify the influence and satisfaction levels for the 77 techniques enabling green performance on multi-family housing projects, this study targeted practical construction engineers with experience in building such projects in the construction industry. A total of 43 potential respondents were invited for the survey and they were asked for their opinion concerning the 77 techniques that they had significant experience of.

At the conclusion of these data collection efforts, 24 respondents of the 43 provided at least partial responses to the questionnaire survey, and 12 responses were complete. The number of respondents appears relatively small but it was important to find people who met the following narrow qualifications: (i) significant experience with the 77 techniques, and (ii) ability to assess both the level of influence of the techniques on achieving green performance as well as the level of satisfaction with the techniques' current technical maturity.

4.2 Survey Results

The survey responses showed that the average work career of all respondents in the construction industry was 16.5 years, and the average number of years they had been conducting green construction work was approximately six years.

To verify the consistency of the survey results, this study calculated the Chronbach alpha value, which was used to determine the accuracy of the results using multivariate data analysis (Peter, 1979; Sharma, 1996; and Wong and Cheung, 2005). Generally, if a Chronbach alpha value is more than 0.7, the collected data is considered to have significant consistency; and if it is over 0.6, it is believed to be suitable for consideration (Cho et al., 2009). Table 5 lists two survey items (influence measurement and satisfaction measurement) with high alpha values of 0.929 and 0.925, respectively. Consequently, they were considered to have excellent internal consistency.

Table 5. Reliability Test of the Survey Results

| Survey items | Influence measurement | Satisfaction measurement |
|--------------|------------------------|--------------------------|
| Chronbach alpha value | 0.929 | 0.925 |

5. Findings and Discussion

Before conducting the ISA procedure, this study suggested mean values for the responses per group of techniques (i.e. 1-A to 6-A) in terms of their influence and satisfaction levels, as shown in Fig.2. The results showed that the green techniques for windows and doors in houses (4-A) were perceived to exhibit the largest difference between the influence and satisfaction levels (i.e. 4.06 to 3.17). In addition, the techniques comprised of electrical installations (6-A) and thermal insulation (3-A) were identified with the fields requiring an industrial endeavor to reduce the gap between the influence and satisfaction levels (i.e. 3.83 to 3.29 and 3.71 to 3.21, respectively). The techniques regarding photovoltaics (i.e. 1-A) and finishing materials (i.e. 3-B) were perceived as the techniques satisfying the current needs from industry because the mean satisfaction measurements exceeded the influence measurements.

Fig.2. Measurement Results Per Group of Techniques

By applying the ISA method to the data collected by the survey and interpreting the results, this study could recommend opportunity, emerging, and established techniques to achieve green performance in multi-family housing projects. Tables 6. to 8. and Figs.3. to 5. present those techniques classified as opportunity, emerging or established technologies based on the rubric presented previously.
delivery of green performance in multi-family housing projects. In addition, thermal insulation techniques and electronic equipment for homes are perceived as still requiring improvement before applying them.

The opportunity technologies were characterized according to their high level of influence in achieving green performance and low relative satisfaction as well as presenting opportunities for high industry pay-off as a result of further research and development efforts to enhance their performance and meet the needs of the industry.

5.2 Emerging Techniques

The following 38 emerging technologies were identified, as shown in Fig. 4. and Table 7.: super thermal insulation materials (3-A1), mineral wool inserted - half drying insulation (3-A3), mineral wool inserted - drying insulation (3-A4), finishing materials controlling humidity (3-B1), finishing materials incorporating bio tech, (3-B2), materials reducing harmful substances (3-B3), mineral paint (3-B4), radiant heat panel on ceiling (3-C1), storage sheet accumulating latent heat (3-C2), recycled wood (3-C3), eco-friendly mortar (3-C6), eco-friendly concrete

Table 7. Descriptive Statistics of the Emerging Techniques

| ID  | Influence measurement | Satisfaction measurement |
|-----|-----------------------|--------------------------|
|     | μ  | σ | μ  | σ |
| 1-A2 | 3.17 | 1.17 | 3.33 | 0.82 |
| 1-A4 | 3.83 | 0.75 | 3.83 | 0.75 |
| 1-A5 | 3.83 | 1.17 | 3.33 | 1.21 |
| 1-A9 | 3.67 | 1.03 | 2.83 | 1.17 |
| 1-B2 | 3.67 | 1.03 | 3.33 | 1.21 |
| 1-B3 | 3.50 | 1.05 | 2.67 | 0.82 |
| 1-B7 | 3.83 | 0.75 | 2.83 | 0.75 |
| 1-C2 | 3.50 | 1.05 | 2.33 | 0.82 |
| 1-C3 | 3.33 | 1.21 | 3.83 | 0.75 |
| 2-A1 | 4.00 | 0.89 | 3.17 | 0.98 |
| 2-A4 | 3.50 | 1.22 | 3.83 | 0.98 |
| 2-B3 | 4.17 | 0.98 | 3.83 | 0.98 |
| 2-B4 | 4.17 | 0.41 | 3.83 | 0.72 |
| 2-B5 | 3.33 | 1.37 | 3.33 | 1.03 |
| 3-A1 | 3.83 | 1.33 | 2.83 | 1.17 |
| 3-A3 | 4.17 | 0.98 | 3.00 | 0.63 |
| 3-A4 | 4.17 | 0.98 | 3.00 | 0.63 |
| 3-B1 | 3.67 | 0.82 | 2.83 | 1.33 |
| 3-B2 | 3.17 | 0.75 | 2.33 | 1.37 |
| 3-B3 | 4.00 | 0.89 | 3.50 | 1.22 |
| 3-B4 | 3.33 | 0.52 | 3.50 | 0.84 |
| 3-C1 | 3.83 | 0.98 | 2.50 | 0.84 |
| 3-C2 | 3.67 | 0.82 | 2.50 | 0.84 |
| 3-C3 | 3.17 | 1.17 | 3.17 | 1.17 |
| 3-C6 | 3.50 | 0.84 | 3.50 | 0.84 |
| 3-C7 | 3.50 | 0.84 | 3.50 | 0.84 |
| 3-C9 | 3.67 | 1.03 | 2.00 | 0.89 |
| 4-A2 | 4.00 | 0.63 | 3.67 | 0.82 |
| 4-A3 | 4.00 | 0.89 | 3.67 | 0.82 |
| 4-A4 | 4.17 | 0.75 | 3.00 | 0.63 |
| 4-A5 | 4.17 | 0.75 | 3.83 | 1.33 |
| 4-A6 | 3.50 | 1.05 | 2.83 | 0.75 |
| 5-A1 | 3.20 | 0.84 | 3.60 | 0.89 |
| 6-A1 | 3.17 | 0.98 | 2.00 | 0.71 |
| 6-A5 | 3.83 | 0.75 | 3.67 | 0.82 |
| 6-A6 | 4.17 | 0.41 | 3.50 | 0.84 |
| 6-A7 | 3.17 | 0.75 | 3.00 | 1.41 |
| 6-A10 | 3.50 | 1.05 | 3.33 | 1.21 |

※ μ: mean value of all responses, σ: standard deviation
From the viewpoint of the components, there were 13 techniques related to green materials (i.e. techniques included in Table 3); nine techniques using renewable energy (i.e. Table 1); five techniques using natural resources (i.e. Table 2); five techniques related to windows and doors; five techniques related to electrical installations; and one technique related to bathroom products.

The results showed that the techniques incorporating eco-friendly items, including green materials, renewable energy, and natural resources, would become a challenge in the multi-family construction industry to ensure green performance in the future. The emerging technologies were characterized according to their average influence and low relative satisfaction. Therefore, these technologies present the opportunity for moderate industry pay-off as a result of further research and development efforts to enhance their performance and meet the needs of the industry.

5.3 Established Techniques

Finally, the following 13 established technologies were identified, and are shown in Fig.5 and Table 8: BIPV system installed to façade (1-A1), BIPV system installed to roof (1-A3), lights powered by PV (1-A6), heating system using geothermal heat (1-B1), heat pump (1-B4), rainwater recycled gardening water (2-A5), roof garden system (2-B1), eco-friendly glues (3-B6), eco-friendly flooring materials (3-B7), waterless urinal (5-A2), sense-based water saving faucet (5-A3), shut-off systems of standby power (6-A3), and LED lights (6-A4).

The established technologies were characterized by their high to average influence and high relative satisfaction. Therefore, these technologies currently meet the needs of the industry and a low pay-off can be expected from any further research and development efforts with respect to better green performance in multi-family housing projects.

6. Conclusion

In conjunction with the adoption of the Kyoto Protocol, the Korean government mandated that the construction industry put forth efforts to develop a range of techniques to improve the green performance in multi-family housing projects. Although many techniques have been developed, many of them are not known to the public, making it difficult for project owners, engineers, and designers to confidently find, select, and apply these techniques to their projects. Therefore, this study aimed to not only identify various green performance techniques that have been developed and adopted in the Korean construction industry, but also to assess their level of influence in achieving green performance and satisfaction at their current level of technical maturity. Using the ISA method based on the data from a survey of construction industry experts, this study ultimately recommended nine opportunity, 38 emerging, and 13 established techniques for ensuring the green performance of multi-family housing projects.

These results are expected to assist engineers in applying the identified techniques to their projects appropriately. In addition, this study will also be beneficial to academic researchers in the future development of new techniques based on the techniques identified in this paper. Because this research was conducted based on the techniques addressed in the Korean construction industry, further studies will be needed to evaluate the use of these techniques in other countries. Because this research was conducted based on the opinion of practical construction engineers, the results could be changed by the character of the respondent's occupational category, skill level, and their project.

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Table 8. Descriptive Statistics of the Established Techniques

| ID | Established Techniques | Influence measurement | Satisfaction measurement |
|----|------------------------|-----------------------|--------------------------|
|    |                        | μ         | σ           | μ         | σ           |
| 1-A1 |                        | 3.50   | 1.05 | 4.33 | 0.82 |
| 1-A3 |                        | 4.67   | 0.82 | 4.50 | 0.84 |
| 1-A6 |                        | 3.17   | 1.17 | 4.83 | 0.41 |
| 1-B1 |                        | 4.33   | 0.82 | 4.17 | 0.75 |
| 1-B4 |                        | 3.83   | 1.33 | 4.50 | 0.84 |
| 2-A5 |                        | 4.67   | 1.21 | 4.33 | 0.82 |
| 2-B1 |                        | 4.50   | 0.55 | 4.50 | 0.55 |
| 3-B6 |                        | 3.50   | 0.55 | 4.50 | 0.55 |
| 3-B7 |                        | 3.50   | 0.55 | 4.50 | 0.55 |
| 5-A2 |                        | 4.20   | 0.84 | 4.80 | 0.45 |
| 5-A3 |                        | 4.40   | 0.55 | 4.40 | 0.89 |
| 6-A3 |                        | 4.50   | 0.55 | 4.50 | 0.84 |
| 6-A4 |                        | 4.33   | 0.82 | 4.17 | 0.98 |
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