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Improving energy efficiency
in Vietnamese tube houses
A survey of sustainable challenges
and potentials

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Abstract

Purpose – Refurbishing houses is considered a key measure to improve the energy efficiency of the built environment. However, little is known about the implementation and outcome of housing renovation for energy upgrades in the Vietnamese practice. The purpose of this paper is to investigate the energy performance of the current housing stock in Vietnam and the potential to reduce energy use in households.

Design/methodology/approach – The paper is based on a survey with 153 respondents in three major climatic regions of Vietnam. The survey focusses on building characteristics, environmental performance, energy performance and refurbishment activities. Data collected from the survey were statistically analysed to give insight into the current performance of the housing stock and its energy saving potential.

Findings – This paper concludes that building design and construction, particularly the building envelope, have a significant influence on the occupants’ comfort. However, the energy consumption in houses is not statistically associated with building design and indoor environment. It is suggested that financial status and occupants’ behaviour currently have a strong influence on the household energy use. The survey also showed that refurbishment improves the housing performance, especially if improving the indoor environment was one of the drivers.

Originality/value – There are very few studies on energy use in households in Vietnam, especially with regards to actual energy consumption. This paper brings insights into the actual energy consumption and reveals the “performance gap” in Vietnamese housing stock.

Keywords Refurbishment, Sustainable, Energy efficiency, Vietnam

1. Introduction

Vietnam has made a lot of significant developments in both economic and social fields since the introduction of the economic reform in 1986. The energy sector, which accounts for one-fourth of the national foreign earnings, certainly plays an important role. In order to continue contributing to the sustainable development of Vietnam, the energy sector has to tackle the problems of ensuring adequate energy supply and minimise energy-related environment impacts. According to the summarised overview of primary energy demand-supply balance for the period of 1997–2025, both policy makers and planners

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agree that the energy demand will soon outweigh and double the domestic supply by 2025, see Figure 1 (Do and Sharma, 2011).

Accounting for more than 31 per cent of the total energy consumption in 2012, the residential sector has been addressed as one of the most important sectors that can potentially reduce the total energy consumption in Vietnam, see Figure 2 (IEA, 2012). Various organisations are aware of the importance of saving energy in buildings. Within the framework of the National Energy Efficiency Program for the 2006–2015 period, the Vietnamese Government issued the National Technical Regulation on Energy Efficiency Buildings (NTREEB) which applies both to new buildings and to renovation of existing buildings (MOC, 2017). In addition, the Vietnam Green Building Council was established in 2007 to raise awareness and build capacity for the development of green buildings in Vietnam. The NTREEB only applies to large-scale buildings but not to small houses, although the small houses account for almost 99 per cent of the housing stock (GSO, 2010).

Energy use of households in Vietnam, especially energy consumption of single dwellings, is also rarely investigated. Previous studies focussed on the relationship between

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**Figure 1.** Primary energy demand and supply balance

**Source:** Do and Sharma (2011)

**Figure 2.** Vietnam final total energy consumption by sector in 2012

**Source:** IEA (2012)
building parameters and indoor environment (Nguyen et al., 2011; Ly et al., 2010a) and simulated energy consumption (Vu, 2017). Nguyen et al. (2011) utilised in-situ measurements and building simulations to investigate the design strategies in Vietnamese vernacular dwellings and the thermal performance. Ly et al. (2010a) conducted a housing survey in 4 different cities of Vietnam to examine the climate responsive design of the Vietnamese housing stock. Although there were 350 participants in that survey the results did not take into account the energy consumption. Several architects have claimed their design to be sustainable or “green”. Nevertheless, no post-occupancy monitoring was conducted to verify the actual energy performance of the renovated houses. Vu (2017), for example, presented a case study that aims to achieve a zero energy home standard in Vietnam, but the project was just a single specific example.

Refurbishing houses is considered a key measure in improving energy efficiency in the built environment. The newly constructed buildings have more potential to achieve higher energy performance than refurbished projects which are limited by fixed factors in existing sites. However, the importance of the existing building should not be ignored due to the fact the number of existing buildings far outweigh the number of new building added to the market annually. Moreover, in Vietnam, most of the people own their private homes, which also means they are also the main beneficiary of the refurbished project and lower energy consumption can be one of the main priorities.

Many studies have investigated the energy upgrade potential through housing renovation. Refurbishment plans have proven to reduce the energy use of houses by at least 20 per cent (Burgett et al., 2013). Zavadskas et al. (2008) proposed a model that helps to choose between various retrofitting options. The model was based on a multivariable approach and aimed to select the optimum solution for each project and for each of the housing components. Loussos et al. (2015) has even included the embodied energy in the total energy reduction of a facade after refurbishment. The improvement in energy systems can also improve energy efficiency in the built environment (Jansen, 2013). Since residential buildings account for a large part of the total building stock, housing refurbishment for energy upgrade is expected to contribute substantially to the final energy performance of the building sector. Due to the lack of energy efficiency studies, there is an urgent need for a study that explores the current energy use and potential for energy upgrade in the housing stock of Vietnam.

This paper aims to investigate the current context of housing refurbishment activities in Vietnam with a special focus on energy consumption. Furthermore, the study intends to figure out the challenges for implementation and the potential improvements of energy efficient retrofitting. Accounting for more than 70 per cent of the current housing stock, tube houses or attached row houses are the main target of this research. Figure 3 illustrates plans of a typical new tube house and a traditional tubehouse.

2. Literature
The first part of the study investigated status of the current housing stock in Vietnam. Most available data of housing are extracted from the national population and housing census which was conducted in 2009 (GSO, 2010). Data from the census are only used to analyse the housing age and typology. The well-known economic reform in Vietnam in 1986 is an important milestone because only after this event, Vietnamese people was able to own or trade their homes. The big change in housing policy has led to a booming in the housing stock. As a results, majority of the current houses were built after 1986 (GSO, 2010). Among the housing typology, private housing was accounted for 99 per cent and attached row houses alone was accounted for more than 70 per cent (GSO, 2010).
Housing characteristics and housing performance were investigated by a few scholars. Previous studies mainly looked at the climatic design features of the traditional dwellings and the analyses was based on few case studies (Phe and Nishimura, 1991; Nguyen et al., 2011; Le et al., 2013; Ly et al., 2010b). Ly et al. (2010a) conducted a housing survey in four cities in Vietnam and received 350 responses. This survey investigated the condition of the houses such as total floor area, construction material and housing performance which included thermal performance, energy use, water conservation and other criteria. Although the survey covered a broad range of topics, the analysis was mostly descriptive and the results only presented a good overview of the houses but no robust analysis was conducted to give an insight in to the performance of the houses.

The latter part of this study explores the refurbishment potential for sustainability and energy efficiency in Vietnam houses. Refurbishment is considered as one of the key elements in making the built environment sustainable as the existing buildings often account for most parts of the housing stocks. Moreover, old buildings often are less energy efficient since they are not fitted with the latest construction technology.

The implementation of sustainable refurbishment often involves different participants including government (central and local), private sectors (developers, consultants, contractors), knowledge institutions (universities, research institutes) and occupants. Government policy is identified as a major driver for sustainable retrofit in many countries. Swan et al. (2013) found that adoption of sustainable retrofit in UK social housing was strongly driven by government-funded programmes. As a result, low technology solutions were mainly used in UK social housing projects. In Malaysia, the main barrier for sustainable construction was identified as the government’s lack of incentive programmes and the slow progress in revising regulation (Abidin et al., 2013). The Green Deal, a major new energy policy in UK, was found to raise the awareness of the home owners towards energy efficiency renovation (Pettifor et al., 2015).

The very first legislation for energy efficiency buildings in Vietnam was the NTREEB issued in 2013 and updated in 2017 (MOC, 2017). It provides mandatory technical standards in design, construction or retrofit of buildings with a gross floor area of 2,500 m² or larger of the following types: offices, hotels, hospitals, schools, commercials, services and residential. The requirements of this regulation apply to four main subjects: building envelope, ventilation and air-conditioning systems, lighting systems and other electrical equipment (electric motors, water heating system and so on). It is important to note that for refurbishing projects, the mandatory requirements apply to the corresponding systems.
to be retrofitted. Private housing, which has a total floor area which rarely exceed 300 m², is not within the scope of this regulation. However, the available regulation for larger scale apartment buildings is an important basis to develop a suitable regulation for the small scale residential units.

The private sector, including developers and contractors, are mostly commercial organisations, hence depend significantly on the government incentive programmes, as mentioned above. Low cost technology was preferred by the providers because cutting-edge technology was often perceived as less effective (Swan et al., 2013). Abidin et al. (2013) also claimed that one of the challenges is the high cost of importing green technology.

Occupants, or home owners in case of private housing, also play important roles in sustainable housing refurbishment. A survey study in Sweden pointed out that 70 to 90 per cent of the people did not have the intention of applying energy efficiency measures in their houses over the next ten years, mostly because they were satisfied with their current homes regarding physical condition, thermal performance and aesthetics (Nair et al., 2010). Energy efficiency policy, the Green Deal in UK for example, can potentially motivate home owners to adopt a more sustainable approach when they are thinking about how to improve their homes (Pettifor et al., 2015). However, actual financial benefit was seen as a common challenge for home owners when energy efficiency measures are considered (Pettifor et al., 2015; Nair et al., 2010). Other barriers to the energy efficiency intervention were also defined as aesthetic tastes and effect on lifestyle (Crosbie and Baker, 2010).

Actual energy savings also depend largely on user behaviour. Nguyen and Aiello (2013) studied different projects in Europe and the USA and found that unaware behaviour can add up to one-third of a building designed energy performance. Post occupancy evaluation (POE) also showed impact of inhabitants’ behaviour over building performance. Gill et al. (2010) performed an POE in a site of UK EcoHomes with an “excellent” rating and found out energy efficiency behaviour can explain 51 and 37 per cent of the variance in heat and electricity usage between dwellings.

Energy efficiency refurbishment is still a new concept and is not popular in the Vietnamese housing stock. Therefore, this study aims at investigating the potential for energy upgrading in the existing houses, mainly focussing on the user/home owner’s perspective.

3. Methodology
This research includes a survey on housing, energy consumption and refurbishment. The set-up of the survey is based on the results of the interviews conducted in 2016 (Nguyen et al., 2016) and several studies on housing in Vietnam (Ly et al., 2010a; Nguyen et al., 2011). The survey is an online questionnaire in Vietnamese created with Google Form and was sent to Vietnamese respondents through e-mail in March and April of 2016. Respondents were asked to answer 38 questions which were divided into five parts: general information, housing information, housing environment, energy consumption and housing refurbishment. Housing information was recorded mainly through multiple choice questions. A summary of the questions and answers is shown in Tables I–III. Likert-type scale and semantic differential scale questions were asked to acquire users’ perception of the indoor environment, energy bills and refurbishment priority, corresponding to the results shown in Figures 4, 16 and 17. The first ten participants were from the network of the first author. Some were also asked to provide additional evidence, such as energy bills or photos, to support their answers. Doubts or uncertainties were discussed in the first few cases to make sure the questions were clear and understood correctly. Each of the respondents was then asked to spread the questionnaire to the people in their contact list. This procedure was repeated again and again until the survey no longer accepted respondents, which was after two months. In total, 153 households...
participated in this survey. Although the selection of the respondents was random, the first ten surveys were sent out to the people in the network of the authors so they are more or less involved in the built environment field and well-aware of technical aspects. The follow-up respondents are randomly selected but was also in the network of the previous ones so they are more likely to be well-educated and know what the questions were about. Moreover, in all the questions, there are always an option “Others or I don’t know”. Therefore, the responses are reliable and can be used for analysis. Data were inspected for outliers but no value was found to be excludable. The results of the survey were analysed by SPSS software, version 24.0.

Data collection
From the collected data, the following information was selected for analysis.

<table>
<thead>
<tr>
<th>Houses' characteristics/performance</th>
<th>Red/Bad</th>
<th>Yellow/Neutral</th>
<th>Green/Good</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orientation</td>
<td>West, South West</td>
<td>North, North East, North west</td>
<td>South, South East, East</td>
</tr>
<tr>
<td>External wall</td>
<td>Single wall without insulation</td>
<td>Double wall without insulation</td>
<td>Double wall with insulation</td>
</tr>
<tr>
<td>Roof</td>
<td>Roof without insulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windows</td>
<td>Single glazed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Courtyard existence</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar control</td>
<td>Curtain or none</td>
<td>Double layer of windows No shading device</td>
<td>Double layer of window Shading device</td>
</tr>
<tr>
<td>Use of energy efficiency equipment</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use of solar collectors</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use of air-conditioners</td>
<td>Frequently</td>
<td>Yes</td>
<td>Infrequently, not in use</td>
</tr>
<tr>
<td>Number of cases</td>
<td>46</td>
<td>39</td>
<td>68</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>House colour</th>
<th>Red</th>
<th>Yellow</th>
<th>Green</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>46</td>
<td>39</td>
<td>68</td>
<td>153</td>
</tr>
<tr>
<td>Respondents' age</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 25</td>
<td>8</td>
<td>9</td>
<td>7</td>
<td>24</td>
</tr>
<tr>
<td>25–40</td>
<td>35</td>
<td>29</td>
<td>54</td>
<td>118</td>
</tr>
<tr>
<td>&gt; 40</td>
<td>3</td>
<td>1</td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td>Number of occupants</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1–2</td>
<td>9</td>
<td>14</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>13</td>
<td>7</td>
<td>23</td>
<td>28</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>6</td>
<td>16</td>
<td>43</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>5</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>&gt; 5</td>
<td>9</td>
<td>14</td>
<td>3</td>
<td>17</td>
</tr>
<tr>
<td>Tenure status</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Privately own</td>
<td>30</td>
<td>25</td>
<td>63</td>
<td>118</td>
</tr>
<tr>
<td>Non-privately own</td>
<td>16</td>
<td>14</td>
<td>5</td>
<td>35</td>
</tr>
<tr>
<td>Climatic region</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>34</td>
<td>32</td>
<td>61</td>
<td>127</td>
</tr>
<tr>
<td>Centre and South</td>
<td>12</td>
<td>7</td>
<td>7</td>
<td>26</td>
</tr>
</tbody>
</table>

Table I. Summary of houses categories/colour coding

Table II. Characteristics of the study population

Vietnamese tube houses
<table>
<thead>
<tr>
<th>Housing typology</th>
<th>Apartment (%)</th>
<th>Attached (%)</th>
<th>Detached (%)</th>
<th>Semi-detached (%)</th>
<th>Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>43</td>
<td>28</td>
<td>95</td>
<td>62.1</td>
<td>13</td>
</tr>
<tr>
<td><strong>Region</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>35</td>
<td>22.9</td>
<td>84</td>
<td>54.9</td>
<td>8</td>
</tr>
<tr>
<td>Centre and South</td>
<td>8</td>
<td>5.2</td>
<td>11</td>
<td>7.2</td>
<td>5</td>
</tr>
<tr>
<td><strong>Building age</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–10</td>
<td>22</td>
<td>14.4</td>
<td>46</td>
<td>30.1</td>
<td>6</td>
</tr>
<tr>
<td>10–20</td>
<td>13</td>
<td>8.5</td>
<td>34</td>
<td>22.2</td>
<td>4</td>
</tr>
<tr>
<td>&gt; 20</td>
<td>7</td>
<td>4.6</td>
<td>13</td>
<td>8.5</td>
<td>3</td>
</tr>
<tr>
<td><strong>Function</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixed-use</td>
<td>7</td>
<td>4.6</td>
<td>14</td>
<td>9.2</td>
<td>1</td>
</tr>
<tr>
<td>Residential</td>
<td>36</td>
<td>23.5</td>
<td>81</td>
<td>52.9</td>
<td>12</td>
</tr>
<tr>
<td><strong>Orientation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>East, South, South East</td>
<td>17</td>
<td>11.1</td>
<td>33</td>
<td>21.6</td>
<td>8</td>
</tr>
<tr>
<td>North, North East, North West</td>
<td>9</td>
<td>5.9</td>
<td>26</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>West, South West</td>
<td>10</td>
<td>6.6</td>
<td>29</td>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td><strong>No. of floor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>43</td>
<td>28.1</td>
<td>4</td>
<td>2.6</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0.0</td>
<td>13</td>
<td>8.5</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0.0</td>
<td>35</td>
<td>22.9</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0.0</td>
<td>29</td>
<td>19.0</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0.0</td>
<td>14</td>
<td>9.2</td>
<td>1</td>
</tr>
<tr>
<td><strong>Floor area</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 40</td>
<td>10</td>
<td>6.5</td>
<td>11</td>
<td>7.2</td>
<td>0</td>
</tr>
<tr>
<td>40–80</td>
<td>13</td>
<td>8.5</td>
<td>16</td>
<td>10.5</td>
<td>0</td>
</tr>
<tr>
<td>80–120</td>
<td>17</td>
<td>11.1</td>
<td>23</td>
<td>15.0</td>
<td>2</td>
</tr>
<tr>
<td>120–200</td>
<td>1</td>
<td>0.7</td>
<td>19</td>
<td>12.4</td>
<td>6</td>
</tr>
<tr>
<td>&gt; 200</td>
<td>1</td>
<td>0.7</td>
<td>22</td>
<td>14.4</td>
<td>3</td>
</tr>
<tr>
<td><strong>Structure</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load-bearing wall</td>
<td>7</td>
<td>4.6</td>
<td>24</td>
<td>15.7</td>
<td>2</td>
</tr>
<tr>
<td>Reinforced concrete</td>
<td>27</td>
<td>17.6</td>
<td>60</td>
<td>39.2</td>
<td>7</td>
</tr>
<tr>
<td>Steel structure</td>
<td>1</td>
<td>0.7</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td>Wooden structure</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
<td>0.0</td>
<td>1</td>
</tr>
<tr>
<td><strong>External wall</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brick wall 100–150 mm, no insulation</td>
<td>13</td>
<td>8.5</td>
<td>35</td>
<td>22.9</td>
<td>3</td>
</tr>
<tr>
<td>Brick wall 100–150 mm, with insulation</td>
<td>1</td>
<td>0.7</td>
<td>7</td>
<td>4.6</td>
<td>0</td>
</tr>
<tr>
<td>Brick wall 200–250 mm, no insulation</td>
<td>10</td>
<td>6.5</td>
<td>35</td>
<td>22.9</td>
<td>5</td>
</tr>
<tr>
<td>Brick wall 200–250 mm, with insulation</td>
<td>0</td>
<td>0.0</td>
<td>2</td>
<td>1.3</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>19</td>
<td>12.4</td>
<td>16</td>
<td>10.5</td>
<td>4</td>
</tr>
</tbody>
</table>

**Table III.** Housing characteristics of the survey in 2016 among Vietnamese inhabitants (continued)
Building design and construction information was recorded by asking multiple choice questions that specify the housing design and construction. For example, one can indicate if the house has a west orientation, double layer external walls with insulation, an integrated inner courtyard, shading devices, solar collectors and energy-efficient electrical appliances. For energy consumption data, occupants were asked minimum and maximum monthly electrical consumption (in kWh) and average monthly gas consumption, if applicable. Data on gas use can be given on an average monthly basis since in Vietnam gas is mostly used for cooking purposes. Gas is converted into kWh using the conversion rate of 1 kg gas ⇒ 13.6 kWh (Hahn, 2010) and then summed with electrical use to generate the monthly and annual total energy consumption. Total energy use is divided by the number of occupants to provide an energy use index.

The Indoor environment was assessed by three factors: daylight, thermal environment and natural ventilation. People were asked to indicate their perceived comfort level of the

<table>
<thead>
<tr>
<th>Housing typology</th>
<th>Apartment (%)</th>
<th>Attached (%)</th>
<th>Detached (%)</th>
<th>Semi-detached (%)</th>
<th>Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforced concrete, without insulation</td>
<td>8</td>
<td>5.2</td>
<td>21</td>
<td>13.7</td>
<td>0</td>
</tr>
<tr>
<td>Steel frame with tiling, with insulation</td>
<td>2</td>
<td>1.3</td>
<td>13</td>
<td>8.5</td>
<td>5</td>
</tr>
<tr>
<td>Steel frame with tiling, without insulation</td>
<td>2</td>
<td>1.3</td>
<td>7</td>
<td>4.6</td>
<td>1</td>
</tr>
<tr>
<td><strong>Ventilation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side window</td>
<td>40</td>
<td>26.1</td>
<td>47</td>
<td>30.7</td>
<td>13</td>
</tr>
<tr>
<td>Inner courtyard</td>
<td>1</td>
<td>0.7</td>
<td>12</td>
<td>7.8</td>
<td>0</td>
</tr>
<tr>
<td>Light well</td>
<td>2</td>
<td>1.3</td>
<td>36</td>
<td>23.5</td>
<td>0</td>
</tr>
<tr>
<td><strong>Solar control</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shading devices</td>
<td>13</td>
<td>8.5</td>
<td>44</td>
<td>28.8</td>
<td>8</td>
</tr>
<tr>
<td>Double layer of windows</td>
<td>5</td>
<td>3.3</td>
<td>17</td>
<td>11.1</td>
<td>2</td>
</tr>
<tr>
<td>Curtain</td>
<td>20</td>
<td>13.1</td>
<td>25</td>
<td>16.3</td>
<td>3</td>
</tr>
<tr>
<td>Other</td>
<td>5</td>
<td>3.3</td>
<td>9</td>
<td>5.9</td>
<td>0</td>
</tr>
<tr>
<td><strong>Energy source</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Electricity only</td>
<td>22</td>
<td>14.4</td>
<td>29</td>
<td>19.0</td>
<td>2</td>
</tr>
<tr>
<td>Electricity and gas</td>
<td>21</td>
<td>13.7</td>
<td>66</td>
<td>43.1</td>
<td>11</td>
</tr>
<tr>
<td><strong>No. of air-conditioners</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>4</td>
<td>2.6</td>
<td>11</td>
<td>7.2</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>17</td>
<td>11.1</td>
<td>23</td>
<td>15.0</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>6.5</td>
<td>34</td>
<td>22.2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>5.9</td>
<td>17</td>
<td>11.1</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>1.3</td>
<td>5</td>
<td>3.3</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>0.7</td>
<td>5</td>
<td>3.3</td>
<td>2</td>
</tr>
<tr>
<td><strong>No. of electric water heaters (for bathroom)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>5</td>
<td>3.3</td>
<td>5</td>
<td>3.3</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>25</td>
<td>16.3</td>
<td>37</td>
<td>24.2</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>13</td>
<td>8.5</td>
<td>30</td>
<td>19.6</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0.0</td>
<td>16</td>
<td>10.5</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0.0</td>
<td>3</td>
<td>2.0</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0.0</td>
<td>4</td>
<td>2.6</td>
<td>1</td>
</tr>
<tr>
<td><strong>Solar hot water (solar collectors)</strong></td>
<td>3</td>
<td>2.0</td>
<td>26</td>
<td>17.0</td>
<td>4</td>
</tr>
<tr>
<td><strong>Energy efficiency equipment</strong></td>
<td>18</td>
<td>11.8</td>
<td>46</td>
<td>30.1</td>
<td>7</td>
</tr>
</tbody>
</table>

Table III. Vietnamese tube houses
living spaces. A five-point scale from 1 to 5 was used in which 1 is very unsatisfactory and 5 very satisfactory. The questions had to be answered separately for Summer (May to July) and Winter (November to January) conditions, even though there is no actual Winter in the southern half of the country.

Descriptive analysis

Descriptive statistic such as frequency, percentages, range, were used to summarise the characteristics of the occupants and their homes.

Statistical analysis

The buildings consume a different amount of energy. The statistical analysis aims to relate different factors with housing energy consumption. Energy performance data were associated with different user-related factors. The investigated factors are: occupant perception of energy saving, use of electrical equipment and renewable energy sources.

Categorising housing

There are many factors that have an effect on the performance of houses. Therefore, the buildings were classified into two main groups by using nine criteria: orientation, external walls, windows, roof, courtyard presence, thermal control devices, use of solar collectors, energy-efficient appliances and air-conditioners. In each criterion, the answers were divided into three main groups: poor, unsatisfactory, inefficient or “red”; good, satisfactory, efficient or “green”; and neutral or “yellow”, see Table I. The classification was based on widely accepted literature of bioclimatic and energy-efficient design (Almusaed, 2011; Nguyen, 2013, 2017).

For example, the southeast orientation houses which benefit from the prevailing cool wind in Summer are given one point in “green” category and an single external wall without insulation is considered as 1 “red” point.

Based on the multi-criteria classification method (Roulet et al., 2006), the houses will be categorised as follows:

- a building is “green” if more than 50 per cent of criteria is marked as green;
- a building is “red” if more than 50 per cent of criteria is marked as red; and
- otherwise, the building is “yellow” or not sorted.

This method assumes that all the criteria have the same weight. Although this is debateable, we chose to keep it this way in order to make the analysis easier.
4. Descriptive analysis

Respondents
Among 153 responses recorded, see Table I, there are 142 persons (93 per cent) under the age of 40 and only 11 persons (7 per cent) are 40 or older. Most respondents are aged between 25 and 39, which accounts for 77 per cent (118 persons) of the respondents.

At first, the survey aimed to categorise the responses according to the climatic region where they live, in order to compare the differences in housing and performance. However, 83 per cent (127 people) are located in the Northern part and only 17 per cent lives in the other regions of the country, Central and South.

The number of people in a family ranges from one to seven and the most common composition is a four-person family (28 per cent). Three and five person families accounted for 18 and 20 per cent, respectively, while two-person and six-person families accounted for 12 per cent each. Single persons and big family compositions (more than six occupants) presented less than 10 per cent of the total, see Table II.

The traditional Vietnamese custom is to look for a stable home for the whole family. It is therefore no surprise that 118 persons (77 per cent) stated that they were living in privately owned houses. About 15 per cent of the families were living in a private rental unit and the rest shared rent or otherwise. The fact that majority of the houses are privately owned emphasises the roles of the home owners in the course of energy upgrade of the housing stock. Government policy and incentive programmes are therefore recommended to target directly at the citizens.

Building characteristics
Typology. Tube houses or attached row houses are the main target of this research. They account for 62 per cent of the houses in this survey. About 28 per cent of the houses are apartments and the remaining 10 per cent are detached and semi-detached houses. Among the 95 tube houses, 78 houses (82 per cent) are at least three-storey high, and 77 houses (81 per cent) have a plot size of 60 square meter or lower. Courtyard are presented in 12 houses (13 per cent of the row houses). Densely populated cities have made the contemporary houses narrower and higher which leave less room for daylighting and natural ventilation. Traditional tube houses in Hanoi, Vietnam are mostly one to two storey high and are often bigger and include inner courtyards (Nguyen et al., 2016).

Building age. Most of the houses were built in the last 30 years (95.4 per cent), which means after the Economic reform of 1986. Almost half of the houses (49 per cent) was built in the most recent ten years, about one third (34 per cent) was built in the earlier ten-year period and 12.5 per cent of the houses were constructed in the period from 1986 to 1995. Compared with the national census conducted by the General Statistics Office in 2009, the housing ages in this survey have a similar pattern as the census although the timeline is slightly different. The survey confirms that the houses in Vietnam are mainly built in the last 30 years and this suggests that the potential refurbishment (of houses built in the period between 1986 and 2005) accounts for approximately half of the total housing stock.

Building function. In total, 85 per cent of the houses are used solely for residential purposes and the others have a mix-use type, combining living spaces with offices, commercial activities or workshops. While residential houses are often only partly occupied, office and commercial places are normally fully occupied with more people and devices during the day. Therefore, the energy consumption between these two groups might differ substantially. In some of the analyses regarding energy consumption, mix-used houses are therefore excluded.
Building orientation. People were asked about the main orientation of their house. There were eight options to select from: North, East, South, West and four in between orientations. The orientations do not differ much because many houses are row houses and apartments where the orientation is fixed.

Building construction. Frame: there are two main construction types: reinforced concrete (62 per cent) and load-bearing masonry (21 per cent).

Walls: external walls are all built from clay brick with one layer (100–150 mm) or two layers (200–250 mm), each accounting for half of the houses. In total, 90 per cent of the walls are built without any insulation layer.

Roof: there are two main types of roof constructions: reinforced concrete or a frame (steel or wood) with tiling. Concrete is still the most popular material for roofs, accounting for 75 per cent of the houses. In terms of insulation, 70 per cent of the roofs are constructed with an insulation layer to prevent direct solar gain from the top. The occupants (or architects) appreciated the benefit of roof insulation.

Windows: 82 per cent of the transparent windows are single glazed, while 18 per cent is double glazed. Popular window frames are wood and aluminium (88 per cent) which can be explained by their economic price. In total, 36 times the wooden shutter was mentioned to block direct sunlight and protect the house from overheating.

Discussion: Ly’s et al. (2010a) investigation also found that the reinforced concrete frames and brick external walls are dominant. However, in Ly’s paper, the majority of the houses were roofed with corrugated iron, while in this study, flat concrete roof is the most popular. This is explained by the difference in location where the surveys were taken and hence in the difference in climate and construction practice.

There was lack of energy efficiency factors in the building envelope variation. For example, no green roof or green facade were recorded in the answers. Thermal insulation was mostly applicable to roof construction. However, contemporary tube houses are often three to five storey high and living spaces are mostly located at street level, hence, the insulation effect of the roof does not contribute much to the energy performance of the houses. Moreover, simplicity in the choices for building envelope is also due to the lack of new technology in the market and sustainable design approach. Ly (2012) found that less than 20 per cent of the attached row houses in Vietnam at that time were designed by architects. Instead, they were built upon builder’s experiences and owner’s personal taste. This fact raises a need for educating home owners in a way that they should either consult a qualified architecture firm or they can acquire sustainable knowledge which should be made widely available.

Solar and ventilation control. The main source for natural daylight and ventilation is a side window (82 per cent). A small light-well was mentioned 43 times and inner courtyards were recorded in 14 answers (9 per cent).

Solar control is a popular concept since almost all the houses use one of the following: shading devices, double window layers (transparent and opaque) and curtains.

Building performance

Indoor environment. Respondents were asked to assess their homes’ indoor environment on a five-point scale from 1 to 5, where 1 is very bad, 2 is bad, 3 is neutral, 4 is good and 5 is very good. In general, many occupants expressed their satisfaction with the indoor environment regarding daylight, natural ventilation and thermal comfort both in Summer (May to July) and Winter (November to January). However, the average Summer thermal comfort is less than neutral and 40 persons (26 per cent) indicated that the thermal environment in their house is bad or very bad (Figure 4).
Ly et al. (2010a, b) also investigated the indoor environment of the Vietnamese houses. Ly also found that the occupant satisfaction with the thermal performance and natural ventilation of their houses. Also in both cases, more people had overheating problems rather than cold issues.

**Energy consumption**

In Vietnam, there are two main energy sources: electricity and gas. The gas is often only used for cooking purposes but not for heating or domestic hot water. In many houses, people replaced cooking on gas by cooking on electricity. In this survey, 35 per cent of the families used only electricity, 65 per cent used both electricity and gas.

The most energy-consuming equipment are the air-conditioner and the water heater (for kitchen and bathroom). According to the responses, 90 per cent of the families use the air-conditioner and 93 per cent of the people have water heaters. The respondents were mainly located in the Northern part of the country where there are two distinct seasons, hot Summer and cold Winter. Therefore, the air-conditioners are mainly turned on in the Summer (more often at night than during the day).

In terms of energy-efficient equipment, the solar collector was mentioned in 22 per cent of the answers and 47 per cent of the respondents use equipment with energy efficient labels. Compared to Ly’s results in 2010, where only 3 per cent of the surveyed houses installed either solar collectors or photovoltaic cells or energy efficiency equipment.

5. **Energy performance indicator**

The paper investigates the relationship between energy consumption and residential building characteristics. Energy consumption was measured in kWh where gas consumption is also converted into kWh using the exchange rate of 1 kg gas $= 13.6 \text{kWh}$ (Hahn, 2010). Houses with additional functions, other than residential, are excluded from this part. However, absolute monthly energy consumptions are not comparable since the houses were different in size as well as number of occupants. This part identifies an energy performance index that will be used to compare houses’ performance.

The energy consumption from survey data were the maximum and minimum monthly energy bills. Correlation between the maximum and minimum electricity consumption was examined and a linear relationship between them was found, see Figure 5. The “goodness of fit value”, $R^2 = 0.752$ and the significance is $p < 0.001$. The regression line is then given by: max monthly energy $= (204 \pm 68) \cdot 10^3 + (1.56 \pm 0.13) \times$ minimum monthly energy. Because of the direct relationship between the maximum and minimum monthly energy, the analysis is continued with only the maximum monthly energy.

**Non-building related aspects**

Furthermore, the energy performance possibly depends on non-building related aspects such as the floor area and the number of occupants. It is found that there is a linear relationship between the maximum monthly energy use and the number of occupants.

The regression equation is as follows: max monthly electricity $= (84 \pm 125) \cdot 10^3 + (200 \pm 30) \cdot 10^3 \times$ number of occupants.

The coefficient of determination, $R^2 = 0.563$ and the correlation is significant with $p < 0.001$.

There is also a correlation between energy use and the total floor area, see Figure 6. The floor area and the number of occupants have a relationship with the energy consumption. Among them, the number of occupants is the one with the strongest correlation. The next part investigates if the floor area depends on the number of occupants. If that is the case, the effect of the floor area is determined by the number of occupants,
making the maximum monthly energy demand per occupant the main parameter when investigating the effect of the building on the energy demand.

Figure 7 shows the relationship between the number of occupants and the total floor area. According to the regression analysis, the $R^2 = 0.378$. Considering the data and the graphs, the correlation is not extremely good, but good enough to assume that the main influence on the energy demand is the number of occupants. The aspect of total floor area is the secondary parameter.

6. Results and discussion

**Correlation between energy consumption and overall building characteristics**

The energy consumption and the indoor environment of the houses were associated with each of the building characteristics to see which factors have more effect on the overall performance of the houses. The Spearman correlation method was used to examine the relationship between building performance and building characteristic, see Table IV.

The building envelope, specifically the external walls and roof, have a considerable impact on the perceived comfort of the occupants at 0.05 and 0.1 level of significance, respectively. Orientation and solar control devices also have some correlation, though minor, with the indoor environment of the houses. On the other hand, energy consumption does not show any correlation with the building design and construction but has a weak
correlation with the use of energy efficiency equipment and solar collectors. The indoor environment also does not show any statistical correlation with the final energy use of a household in this analysis.

**Relation between energy consumption and facade insulation**

External walls and roof construction did not show any statistical relation to the energy performance of the houses. In many cases, the houses with better insulation even consumed more energy than ones with insulated facade, see Figures 8 and 9. According to the responses, the majority of the houses had similar facade details, including brick walls without insulation, single glazing windows and concrete roof with insulation. Such practice might have been widely accepted among the builders as well as home owners.

Discussion: for external walls, the question of whether or not insulation helps reduce energy consumption is still debatable. Common practice did not record often the existence of insulation. Traditional architecture also mostly appreciated lightweight facade, without...
insulation in order to get rid of unwanted heat as fast as possible (Nguyen et al., 2011). However, the national technical regulation of energy efficient buildings required large-scale buildings to have a high performance facade, with certain level of insulation (MOC, 2017). The current regulation mostly applies to offices and commercial buildings which are air-conditioned most of the occupied period. High performance facades in this case play a role in preventing the “cold loss”. In residential buildings, the use of air-conditioners is subject to

**Figure 8.**
Energy use of different external walls types

**Notes:** Left: scatterplot graph of external walls type and mean of maximum monthly energy consumption per person (kWh). Right: number of cases with different types of external walls

**Figure 9.**
Energy use of different roof types

**Notes:** Left: scatterplot graph of roof type and mean of maximum monthly energy consumption per person (kWh). Right: number of cases with different types of roof
the behaviour of the occupants. A high performance facade might accumulate unwanted heat and create overheating problem but at the same time benefit a frequent air-conditioner user. Therefore, it is suggested that more comprehensive research should be conducted to quantify actual outcome of high performance facade before putting them into regulation for private housing in Vietnam.

For the concrete roofs, the maximum monthly energy consumption per person is higher for roofs with insulation than for roofs without insulation. For the steel frame roofs, the effect of insulation is positive, therefore steel roofs with insulation will have a lower energy demand. Concrete flat roofs are most popular and mainly applied for houses higher than three stories. In this case, the roofs normally cover unoccupied spaces such as an altar room or storage. On the other hand, simple steel-frame structure roofs are generally applied to lower dwellings with one or two stories and the roofs are normally directly above the living spaces. That might explain the difference in the efficiency of insulation in the roof detail.

According to the analysis, insulation leads to a higher energy demand. It might be because of the low number of houses with insulation compared to the uninsulated ones. Moreover, the lack of correlation between building characteristics and energy performance might also be due to the difference between the predicted and the actual energy consumption, or “performance gap”, which was discussed in many researches (IEA, 2013; Ortiz et al., 2017). Among the causes for such a performance gap, occupant behaviour is defined as a heavily influential factor (Demanuele et al., 2010). On the other hand, Kurvers et al. (2013) indicated that housing design that ignores climate conditions might lead to a greater performance gap compared to the climate-oriented ones. Therefore, further studies are recommended to investigate the cause for the “performance gap” in Vietnam and how to minimise it.

Relation between energy consumption, indoor comfort and the use of electrical equipment

Electric appliances are often ignored in the prediction of electrical consumption, as suggested by Majcen (2016). This phenomenon might lead to greater variation in the performance gap in Vietnam where electrical equipment uses most of the energy. Therefore, although no statistically significant effect is found when the buildings are divided in three groups (green, orange and red), the high significance with low p-value suggests to further investigate the relationship between the energy consumption and the amount of electrical equipment. Table V and Figure 10 illustrate the regression analysis and scatter plot of energy consumption in relation with the number of air-conditioners and water-heaters.

According to the regression analysis, one more air-conditioner and one more electric boiler increases the monthly energy consumption by 61 kWh and 83 kWh, respectively. If the equipment is considered separately, 114 kWh would be consumed monthly for each of air-conditioner unit and 138 kWh for an additional water boiler, see Figure 8. Note that the mean household’s monthly energy consumption is 514 kWh. On average, 244 kWh of electrical energy was consumed for other things (lighting, washing machine, TV, fridge and so on). Although it seems obvious that an increased use of electrical equipment leads to

<table>
<thead>
<tr>
<th>Model 1</th>
<th>Unstandardised coefficients</th>
<th>Standardised coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>SE</td>
</tr>
<tr>
<td>(Constant)</td>
<td>244</td>
<td>35</td>
</tr>
<tr>
<td>Number of air-conditioners</td>
<td>61</td>
<td>21</td>
</tr>
<tr>
<td>Electricity water heater</td>
<td>83</td>
<td>25</td>
</tr>
</tbody>
</table>

Table V. Regression analysis showing relationship between monthly energy consumption (kWh) and number of air-conditioners and electrical water-heaters.
a larger use of energy, it warrants further investigation to find out how to reduce energy in houses.

**Discussion:** in general, 90 per cent of the houses have air-conditioners to improve their indoor environment (see Table VI). Notably, all the houses which claimed to thermally perform very well (5 points) have at least one conditioner. None of them were only naturally ventilated. Similar observations apply to houses which score 4 points (good) in thermal performance. Only one out of 42 houses that score good on indoor environment does not use any air-conditioner.

Most air-conditioned houses own one to three AC units (78 per cent of the total number of cases and 87 per cent of the air-conditioned ones). Among this group, three quarters of the respondents rated their houses as having a neutral or good thermal performance. Well-performing houses are usually not good "enough" to keep the houses air-conditioner free. This means that either houses can perform generally good but not in some extreme weather period or people prefer using active mechanical ventilation in any thermal condition.

Houses that perform badly in terms of thermal comfort in Summer are less likely to have air-conditioners in their homes. For instance, 24 per cent of the "very bad" and 31 per cent of

**Table VI.**

Crosstab table of number of air-conditioners and self-assessment of thermal comfort in Summer

<table>
<thead>
<tr>
<th>Summer thermal comfort</th>
<th>0</th>
<th>1–2</th>
<th>3–5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Very bad (1)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count</td>
<td>5</td>
<td>8</td>
<td>8</td>
<td>21</td>
</tr>
<tr>
<td>% within Summer thermal comfort</td>
<td>23.8</td>
<td>38.1</td>
<td>38.1</td>
<td>100.0</td>
</tr>
<tr>
<td><strong>Bad (2)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count</td>
<td>6</td>
<td>11</td>
<td>2</td>
<td>19</td>
</tr>
<tr>
<td>% within Summer thermal comfort</td>
<td>31.6</td>
<td>57.9</td>
<td>10.5</td>
<td>100.0</td>
</tr>
<tr>
<td><strong>Neutral (3)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count</td>
<td>4</td>
<td>44</td>
<td>18</td>
<td>66</td>
</tr>
<tr>
<td>% within Summer thermal comfort</td>
<td>6.1</td>
<td>66.7</td>
<td>27.3</td>
<td>100.0</td>
</tr>
<tr>
<td><strong>Good (4)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count</td>
<td>1</td>
<td>23</td>
<td>18</td>
<td>42</td>
</tr>
<tr>
<td>% within Summer thermal comfort</td>
<td>2.4</td>
<td>54.7</td>
<td>42.8</td>
<td>100.0</td>
</tr>
<tr>
<td><strong>Very good (5)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>% within Summer thermal comfort</td>
<td>0.0</td>
<td>60</td>
<td>40.0</td>
<td>100.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count</td>
<td>16</td>
<td>89</td>
<td>48</td>
<td>153</td>
</tr>
<tr>
<td>% within Summer thermal comfort</td>
<td>10.5</td>
<td>58.2</td>
<td>31.4</td>
<td>100.0</td>
</tr>
</tbody>
</table>
the “bad” indoor comfort houses do not have any air-conditioners, see Table VI. To further test the hypothesis that houses without air-conditioner do not have a good comfort, such houses were further investigated.

Houses that do not use air-conditioner and consume less energy are typically poorly designed in terms of providing good indoor environment and do not take energy efficiency into consideration. Out of 16 houses, 50 per cent were built in the last ten years, and more than 30 per cent were built in the previous decade. In all, 13 people responded to the external wall question, which were all single walls without insulation. Ten out of 14 known roof details did not report a thermal insulation layer. In 13 houses, daylight and natural ventilation comes from windows only. Rates of using a solar hot water system and energy efficiency equipment are both only 25 per cent. In general, ten houses were graded as “red” and only two houses were “green”. They also have not been refurbished recently because they are not permanent houses, the budget is limited or simply because the houses were newly built.

**Other aspects**
The lack of correlation between building performance and building characteristics suggests that there are more reasons for the energy use in houses beside building configurations. In this case, household income could be a responsible factor since people with a lower income might live in poorly designed houses and are more likely to be unable to afford air-conditioners and high energy bills. However, income data is privacy-sensitive and was not acquired in this survey. Instead, the use of electrical equipment and consumed energy are correlated with intermediate factors that somehow refer to income. These factors are housing typology, tenure status and total floor area. In Vietnam, higher income people tend to possess larger privately owned houses and not apartments (Sanghoon et al., 2013).

Figure 11 shows the number of air-conditioners by tenure status and total floor area of the houses. Among 120 private owned houses, only two of them do not have any air-conditioning units while 45 per cent of the rented homes (13 out of 29) was air-conditioner free. Regarding sizes of the houses, smaller residential units are more likely to have less air-conditioners. However, such a correlation does not directly address household income as a driver for the use of electrical equipment, but it also suggests that most rooms still require or are desired to have mechanical ventilation. For this reason, a further investigation on the income of the people as well as a more detailed examination of the case studies is recommended.

**Figure 11.** Characteristics of air-conditioner-free houses.
7. Refurbishment

Refurbishment is a complicated process and the motivations for housing renovation are also complex and usually there is more than one reason for refurbishment. Different reasons led to different levels of intervention ranging from minor repair (redecorating, repairing parts or service) to intensive renovation (expanding space, adding or removing building components to improve the indoor environment, etc.) (see Figure 12).

Older houses are more likely to be in need of refurbishment. About two-third of the houses that are over 20 years old have been refurbished in the last ten years, see Figure 13. This fact also applies when the cases were broken down into separate refurbishment reasons. Recently built houses within the last decade are more likely to be redecorated or repaired. On the other hand, more than 20 year-old houses often have a more complex refurbishment with different activities.

Refurbishment in the last ten years has led to changes in housing performance in terms of indoor environment and energy consumption. Figure 14 illustrates the effects that were indicated by the respondents. In general, the indoor climate was improved, especially with regards to the thermal environment. The energy performance also shows improvement, though minor. This result suggests that housing refurbishment might potentially improve the indoor environment as well as the energy performance even if they are not the main drivers for renovation activities.

Refurbishment in general improves the building performance. Table VII shows the changes in accordance with the refurbishment action. Only changes in thermal and energy performance are shown with respect to four different refurbishment options: redecorate, repair, expand spaces and improve indoor environment. The results show that the improvement rates are the same regardless of the measures involved. For instance,
the building performance remained unchanged or improved for at least 86 per cent of the cases. A minor notice here: repairing damaged parts and improving indoor environment are less likely to make the current situation worse (less than 2 per cent of the cases, whereas these rates in the redecorating and expanding sections ranged from 11 to 14 per cent).

On the other hand, refurbishment activities generally show higher improvement rates in thermal performance than in energy performance. Regarding thermal performance, each measure shows “better” and “much better” results for 59 to 92 per cent of the cases.
These rates only vary from 24 to 40 per cent with regards to energy performance. Such differences can partly be explained by the occupant behaviour and the use of electrical equipment.

Improving the indoor environment is shown to be the most successful measure in improving the building performance compared to others. However, it is the least favourable reason for refurbishment with only 25 cases, only comparable with expanding living spaces with 27 cases. This fact is probably due to the complexity and high cost of an extensive refurbishment which is required by “improving indoor environment” and “expanding living spaces”. Nevertheless, refurbishment decisions are often made with a combination of intentions and, together with the improvements shown above, we can expect a favourable result in energy and indoor environment of housing refurbishment in Vietnam in the near future.

Among the 75 of the houses that were not refurbished recently, 64 per cent of the respondent were satisfied with their homes and did not have the need to improve their current homes. In all, 12 per cent of them wanted to renovate the houses but did not have sufficient funding. The rest 24 per cent of the homes were rented properties so the occupants did not want to or were not allowed to refurbish their houses, see Figure 15.

Occupants perceived energy bills in most cases as not expensive nor cheap. In total, 64 per cent of the respondents stated that the bills were reasonable for them (Figure 16). That explains why energy efficiency is not the high priority when refurbishment measures are considered. Respondents gave high priority to economic factors (mean rank = 2.73) and indoor environment (mean rank = 2.69) (Figure 17). Improving indoor environment was also the on top of the wish lists of the occupants when they were asked about what they want to improve in their current homes, see Figure 17. Although improving the indoor environment can potential reduce the heating and cooling loads, hence reduce energy use in home, the term “energy efficiency” is not yet widely discussed or fully understood among the home owners in Vietnam and it was not given a high credit. Therefore, Vietnamese people are still applying energy efficiency refurbishment measure quite passively. Energy saving results from the refurbishment process will be limited. It is recommended that information campaign announcing benefits of the energy efficiency design measures should be implemented to raise the awareness of the people.

8. Conclusion
This paper presents results of a housing survey in Vietnam, focussing on building characteristics, energy performance and refurbishment activities. There are few studies on the
energy use of households in Vietnam, especially actual energy consumption. Previous studies focussed on the relationship between building parameters and indoor environment (Nguyen et al., 2011; Ly et al., 2010a) and simulated energy consumption (Vu, 2017). This research is not an exhaustive survey of energy performance, building characteristics and refurbishment activities in Vietnam. The respondents and the houses and were not completely randomly selected. This study mainly aims to explore the problems and potentials in the current energy context of Vietnamese houses in order to set up the foundation for future work. The following results are therefore only qualitative and not quantitative.

First, it reveals some insights into the current housing stock of Vietnam. The most popular housing typology in Vietnam is the privately owned, attached, terraced house, which is called the “tube house”. The majority of the residential units studied were built in the last 30 years. Houses in Vietnam have a lot in common in construction practice: reinforced concrete frame, brick masonry wall without insulation and single glazed windows combined with wooden shutters.

Building design and construction have a strong relationship with the occupants’ comfort levels. Better designed houses usually result in more comfortable living experiences. Among different parameters, the building envelope, including external walls and roofs, was found to have the greatest influence on the indoor environment of the houses. This result fully agrees with the work conducted by Nguyen (2013) and partly agrees with Ly’s et al. (2010a) paper where orientation was the main responsible parameter for thermal performance of houses, apart from the building envelope and shading options. Refurbishment activities were also...
likely to have positive effect on thermal performance of living spaces. The majority of houses that are more than 20 years old were recently refurbished and they often included improving indoor environment as a goal along with other reasons.

This paper investigates the actual energy consumption and reveals the “performance gap” in Vietnamese housing stock. Energy use is strongly associated with the use of electrical appliances, particularly air-conditioners. This research also suggests that occupant behaviour depends on the financial status of the occupants. There are people who live in poorly designed houses with bad indoor comfort but they consume less energy because they cannot afford energy-consuming equipment. Houses that perform well thermally still depend on air-conditioners to ensure indoor comfort. Therefore, both innovation design strategies and more detailed legal regulations should be developed in order to aim for better energy performance or zero energy housing stock in Vietnam.

Housing renovation is initially found to enhance building performance. Improvements in the indoor environment are more likely to be reported than a reduction in energy use. Improvements in building performance were found regardless of the renovation actions. However, preliminary results indicate that focusing on improving housing microclimate generally leads to more satisfactory housing performance in Vietnam although such intentions usually require other refurbishment drivers such as expanding living spaces, repairing damaged parts or redecoration. Although budget plays an important role in refurbishment decision making and energy is at the bottom of the priority list, the high desire of improving indoor environment suggests potential energy saving through housing refurbishment.

Results from this survey should be studied quantitatively in the future to better assess the benefit of the different intervention measures on the indoor comfort and energy demand. Building simulation is a good method to investigate variations of building design and facade types. Other components such as greenery systems, which are more difficult to simulate, should be studied through physical experiments.

References


Further reading


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Environmental life cycle analysis of a fixed PV energy system and a two-axis sun tracking PV energy system in a low-energy house in Turkey

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Sakarya University, Sakarya, Turkey

Abstract

Purpose – The purpose of this paper is to propose a fixed PV energy system design and a sun tracking PV energy system design to meet the primitive energy demands of a typical house in Sakarya, Turkey with energy payback times (EPBT) and greenhouse payback times (GPBT) calculations.

Design/methodology/approach – The designs were developed based on the total solar radiation received on the surface of the PV modules. The EPBT and the GPBT of the designs were investigated by utilizing the current embodied energy data of the literature and annual energy output of the proposed systems. The monthly mean total solar radiation, the yearly total solar radiation and the annual energy output of the systems were calculated according to the results of previous studies of authors on 80-W prototypes of a fixed PV energy system tilted at the yearly optimum tilt angle of Sakarya and a two-axis sun tracking PV energy system.

Findings – The annual energy outputs of the fixed system and the tracking system were established to be 10.092 and 10.311 MJ, respectively. EPBT of the systems were estimated 15.347 years for the fixed system and 11.932 years for the tracking systems which were less than the lifespan of PV modules. The greenhouse gas emitted to produce and install the systems were estimated to be 6,899.342 kg for the fixed system and 5,040.097 kg for the tracking system. GPBT of the systems were calculated to be 5.203 and 2.658 years, respectively.

Originality/value – PV energy is clean without greenhouse gas emission during the operation. However, significant emissions occur in the life cycle of PV modules until the installation is completed. Therefore reducing the number of PV modules make great differences in the GPBT of PV energy systems. In this paper, comparisons between the GPBT results of the optimally tilted fixed system and tracking system were performed to discuss the best option by means of environmental concerns.

Keywords Sun tracking, EPBT, GPBT, Optimum tilt angle, PV energy system, Total solar radiation

Paper type Research paper

1. Introduction

The temperature of the combined land and ocean surface have shown warming of 0.85 (0.65–1.06)°C since 1880. The unprecedented increase in the atmospheric concentrations of the greenhouse gases due to fossil fuel use and other human activities has been unequivocally making a significant contribution to this warming (IPCC Working Group I, 2013).

Electricity consumption of buildings has grown by 2.5 percent per year since 2010. That growth increased the building-related emissions faster than the 0.5 percent average annual decrease in CO₂ intensity per kilowatt hour of electricity by energy-efficient building standards (Tracking Progress: Buildings Report, 2017). The 2DS aims to reduce CO₂ emissions of 2013 by almost 60 percent by 2050 (World Energy Outlook Report, 2017). Therefore, the share of buildings in CO₂ emissions needs to be limited by decreasing the average household energy consumption by at least 10 percent adapting the energy efficiency standards and low-carbon building technologies (Tracking Progress: Buildings Report, 2017).

PV energy systems have come to the forefront in reducing the energy use of buildings with several advantages lately (Pathania et al., 2017). These systems supply sustainable and secure energy in the most environmentally friendly way with zero greenhouse gas emission,
noise and impact on nature during the operation. Besides that the roofs of the most buildings provide appropriate surfaces to install PV modules in various combinations (Durrani et al., 2018).

Turkey is recorded to be one of the countries which have enormous PV energy potentials with 3.6 kW h/m²-day of annual average solar radiation and 2,640 h of total annual sunshine hours (Evrendilek and Ertekin, 2003). Ministry of Energy and Natural Resources has reported that only 4 percent of the installed power of Turkey is PV energy based and the main energy sources in electricity generation still comprise of fossil fuels with a share of 70 percent (Ministry of Energy and Natural Resources: Electricity Report, 2017). Nevertheless the local fossil fuel reserves are poor at meeting the related fossil fuel demand. Thus, 64 percent of the coal demand, 99.2 percent of the natural gas demand and 93.6 percent of the oil demand are met by imports (Ministry of Energy and Natural Resources: Electricity Report, 2017; The View of Energy and Natural Resources: Turkey and the World, 2018). Besides the per capita CO₂ emissions were recorded to be 6.07 metric tons in 2015, 122 percent of the emissions in 1990 (Statics of greenhouse gas emissions report: 1990-2015, 2017). Therefore, the dependency on imported fossil fuels and the increasing fossil fuel based greenhouse gas emission impose an obligation to revise the energy policies encouraging renewable energy investments in the country for a sustainable future.

This paper presents a fixed PV energy system design and a sun tracking PV energy system design to meet the primitive energy demands of a typical house in Sakarya, Turkey. The designs were developed based on the total solar radiation received on the surface of the PV modules. The energy payback times (EPBT) and the greenhouse payback times (GPBT) of the designs were investigated by utilizing the current embodied energy data of the literature and annual energy output of the proposed systems. The monthly mean total solar radiation, the yearly total solar radiation and the annual energy output of the systems were calculated according to the results of previous studies of authors on 80-W prototypes of a fixed PV energy system tilted at the yearly optimum tilt angle of Sakarya and a two-axis sun tracking PV energy system.

2. Material and methods

Energy demanding units of the experimental house were selected to supply the primitive needs of daily life (Table I). Table I indicates that the total daily energy need of the house with the fixed system and with the tracking system are 4,240 and 4,255 Wh, respectively. At this point, it was assumed that the dishwasher, the washing machine and the vacuum cleaner were not operated on the same day to minimize the electricity consumption. Thus the maximum total daily energy demands were reduced to 3,077 and 3,093 Wh.

The number of PV modules of the systems was calculated using the following equation (Tsalikis and Martinopoulos, 2015):

\[ E_p = S \times n_p \times H_T, \]

<table>
<thead>
<tr>
<th>Energy units</th>
<th>Unit number</th>
<th>Unit power (W)</th>
<th>Daily operating time (h)</th>
<th>Daily demand (Wh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>4</td>
<td>20</td>
<td>4</td>
<td>320</td>
</tr>
<tr>
<td>Television</td>
<td>1</td>
<td>50</td>
<td>4</td>
<td>200</td>
</tr>
<tr>
<td>Refrigerator</td>
<td>1</td>
<td>35.7</td>
<td>24</td>
<td>857</td>
</tr>
<tr>
<td>Washing machine</td>
<td>1</td>
<td>800</td>
<td>1</td>
<td>800</td>
</tr>
<tr>
<td>Dish washer</td>
<td>1</td>
<td>1,800</td>
<td>1</td>
<td>1,200</td>
</tr>
<tr>
<td>Vacuum cleaner</td>
<td>1</td>
<td>1450</td>
<td>0</td>
<td>363</td>
</tr>
<tr>
<td>Laptop</td>
<td>1</td>
<td>250</td>
<td>2</td>
<td>500</td>
</tr>
<tr>
<td>System motors(a)</td>
<td>2</td>
<td>0.48</td>
<td>14</td>
<td>13.5</td>
</tr>
</tbody>
</table>

Table I.  
Energy demanding units of a typical house

Note: "System motors are units of the tracking PV energy system"
where $S$, $n_p$ and $H_T$ are the module area, the average module efficiency and the total solar radiation, respectively. $S$ and $n_p$ were obtained from the technical specifications of PV modules (Table II).

$H_T$ was estimated by the following equation (Iqbal, 1983):

$$H_T = H_B \times R_B + H_D \times R_D + H \times \rho_g \times \left(1 - \cos \beta \right).$$

(2)

In this equation, $H_B \times R_B$ and $H_D \times R_D$ are the beam solar radiation and diffuse solar radiation on the tilted surface, respectively. $H$ is the global solar radiation, $\rho_g$ is the ground reflectivity coefficient and $\beta$ is the tilt angle of the surface.

PV modules of the fixed system were tilted at the yearly optimum tilt angle of Sakarya which was established to be 32° for Sakarya, Turkey. The monthly mean daily total solar radiation values on the surface tilted at this angle are given in Table III (Aksoy Tirmıkçı and Yavuz, 2018a).

The tracking system designed in this paper tracks the sun by azimuth and altitude angles in two axes (Aksoy Tirmıkçı and Yavuz, 2018b). There are different equations for azimuth angle and altitude angle in current studies. The equations used in this paper are as follows (Szkolay, 2007):

$$azi = \cos^{-1}\left(\frac{\cos \varphi \times \sin \delta - \cos \delta \times \sin \varphi \cos HRA}{\cos alt}\right),$$

(3)

Environmental life cycle analysis

| Maximum power | 250 W |
| Tolerance | ±3% |
| Open circuit voltage | 37.8 V |
| Short circuit current | 8.7 A |
| Maximum power voltage | 31.5 V |
| Maximum power current | 7.94 A |
| Module efficiency | 15.3% |
| Solar cell efficiency | 17.2% |
| Terminal box | IP65 |
| Maximum system voltage | 1000 V DC |
| Operating temperature | -40°C – 80°C |
| Dimensions | 1,650 mm × 992 mm × 40 mm |
| Weight | 17 kg |

Table II. Technical specifications of the PV module of the systems

<table>
<thead>
<tr>
<th>Month</th>
<th>$H_T$ [kWh/m²-day]</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>2.2050</td>
</tr>
<tr>
<td>February</td>
<td>3.2900</td>
</tr>
<tr>
<td>March</td>
<td>3.9989</td>
</tr>
<tr>
<td>April</td>
<td>4.6671</td>
</tr>
<tr>
<td>May</td>
<td>5.2858</td>
</tr>
<tr>
<td>June</td>
<td>5.4967</td>
</tr>
<tr>
<td>July</td>
<td>5.4247</td>
</tr>
<tr>
<td>August</td>
<td>5.3923</td>
</tr>
<tr>
<td>September</td>
<td>4.9814</td>
</tr>
<tr>
<td>October</td>
<td>3.9862</td>
</tr>
<tr>
<td>November</td>
<td>2.6335</td>
</tr>
<tr>
<td>December</td>
<td>1.9844</td>
</tr>
</tbody>
</table>

Table III. The monthly mean daily total solar radiation on the 32° tilted surface
In these equations, $\text{azi}$, $\text{alt}$, $\varphi$, $\delta$ and $\text{HRA}$ are the azimuth angle, the altitude angle, the latitude of the location, the declination angle and the hour angle, respectively.

The proposed tracking system operates hourly between 06:00 and 20:00 every day. The main purpose in tracking is to equalize the sun’s position and the current position of PV modules of the system in terms of azimuth and altitude angles. The tracking steps are as in Figure 1 (Aksoy Tırnakçı and Yavuz, 2015).

The 80-W prototypes were mounted on a feasible roof and observed for six months (July–December) in 2017 (Plate 1). The monthly total energy production of prototypes are given in Table IV. From Table IV, it can be concluded that the tracking system is 54, 46, 54, 45, 48 and 46 percent more efficient than the fixed system in July, August, September, October, November and December, respectively.

3. Results
The design of PV energy systems should be made considering the worst conditions. Table III indicates that the minimum value of the monthly mean daily total solar radiation at the $32^\circ$ tilted surface is obtained in December. Thus, the calculations to determine the number of PV modules were made by using the related data of this month. According to $H_T$ value in December and $S$ and $n_p$ values from Table II, it was found out that at least seven PV

![Figure 1. The tracking steps of the proposed system](image-url)
modules were required to meet the total daily energy need of the house with the fixed system tilted at 32° in the cloudiest days of the year.

The energy production of PV modules is directly related to the total solar radiation received on the surface (Equation (1)). The analysis of 80-W prototypes showed that the energy production of the tracking system in December was 46 percent higher in comparison with the fixed system (Table IV). Therefore, the monthly mean daily total solar radiation of the tracking system in December equals to the monthly mean daily total solar radiation of the fixed system in December multiplied by 1.46, 2.8972[kWh/m²-day]. According to this $H_T$ value and $S$ and $n_p$ values from Table II, it was found out that at least 5 PV modules were required to meet the total daily energy need of the house with the tracking system in the cloudiest days of the year.

PV energy conversion has been an effective technology to mitigate greenhouse gas emissions in recent years, since PV energy is pollution free. However, energy requirements for the manufacturing of PV systems need to be regarded to estimate the net GPBT. EPBT, the ratio of the total embodied energy and annual energy generation of the system, is a significant integrator to observe the decrease in CO₂ emission potential (Lu and Yang, 2010). The total embodied energy of the system includes the energy not only in the extraction of the raw materials but also in processing, transformation and installation to produce a PV module and

<table>
<thead>
<tr>
<th>Month</th>
<th>Fixed system production (Wh)</th>
<th>Tracking system production (Wh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>July</td>
<td>1,383,232</td>
<td>2,130,177</td>
</tr>
<tr>
<td>August</td>
<td>1,234,200</td>
<td>1,801,932</td>
</tr>
<tr>
<td>September</td>
<td>1,164,600</td>
<td>1,630,440</td>
</tr>
<tr>
<td>October</td>
<td>919,600</td>
<td>1,333,420</td>
</tr>
<tr>
<td>November</td>
<td>5,880,00</td>
<td>787,240</td>
</tr>
<tr>
<td>December</td>
<td>475,728</td>
<td>694,563</td>
</tr>
</tbody>
</table>

Table IV. The monthly total energy production of 80-W prototypes
balance of the system (BOS) (Kato et al., 1998). There are different predicted values for the energy requirement of PV modules and BOS in the range of 894–13,428 MJ/m² in current studies (Bhandari et al., 2015). Alsema estimated the total embodied energy of a roof type system with an amorphous crystalline PV module to be 2,470 MJ/m² at 1,700 kWh/m²/year insolation (Alsema, 2000). Kato et al. investigated EPBT in two cases. In the first case they assumed that the processes were operated at the worst conditions with the highest energy requirement. In the second case they improved the conditions and reduced the energy requirement. For the better case they recorded the embodied energy of a mono crystalline PV module for roof installation to be 11,673 MJth/m² at 1,427 kWh/m²/year insolation (Kato et al., 1998). Bizzari et al. proposed a high value of 11,153 MJ/m² for the embodied energy of a roof type PV module and BOS at 1,533 kWh/m²/year insolation (Bizzarri and Morini, 2007). Garcίa-Valverde et al. (2009) recorded another high value of 13,428 MJ/m² for producing and mounting a roof type system at 1,932 kWh/m²/year insolation. Ito et al. (2010) established a smaller value of 1,708 MJ/m² for a ground type application at 1,702 kWh/m²/year insolation. Perpinan et al. investigated the effect of tracking mechanisms on the energy requirement of a PV module and BOS of sun tracking PV energy systems. They recorded the embodied energies of a two-axis sun tracking system and a fixed system to be 60,140 and 51,005 MJp/kWp, respectively (Perpiñan et al., 2009).

The annual solar irradiation is established to be 1,527 kWh/m²/year for Turkey. Using the insolation as the determining integrator, the embodied energy of a PV module and BOS for a fixed PV energy system was assumed to be 11,153 MJ/m² referring to Bizzari et al. The additional energy requirement of tracking system mechanisms of the two-axis tracking system was estimated to be 1,250 MJ/m². Therefore, the total embodied energy of the fixed system and the tracking system were calculated to be 154,892 and 123,037 MJ, respectively.

The annual energy output of the systems was predicted based on the total solar radiation received by PV modules, since there are no recorded data. The annual total solar radiation of the fixed system at 32° was calculated to be 5,384 MJ/m² for Sakarya province. It was observed that the tracking system received 43 percent more solar radiation than the fixed system received annually. Thus, the total solar radiation of the tracking system was 7,968.32 MJ/m², 1.43 times of the total solar radiation of the fixed system. The performance ratio of the systems was assumed to be as high as possible, 90 percent, considering least inefficiencies in energy output. In view of this information, the annual energy output of the fixed system and the tracking system were established to be 10.092 and 10.311 MJ, respectively. EPBT of the systems were estimated by dividing the calculated total embodied energy and the annual energy output. It was found out that EPBT values, 4.43 years for the fixed system and 3.09 years for the tracking system, were less than the lifespan of PV modules.

The greenhouse gas emission factor from electricity production is established 0.478 kg CO₂eq/kWh for Turkey (IEA Policies of Countries: Turkey, 2016). Based on this emission factor and predicted annual energy output of the systems, the annual CO₂ emissions saved by the fixed system and tracking system were calculated to be 1,325,819 and 1,895,921 kg, respectively. The embodied greenhouse gas emissions of the systems were evaluated in terms of PV modules, BOS and inverters. In this paper, the greenhouse gas emission factors for the production of PV modules, BOS and inverters were selected to be 463 (Battisti and Corrado, 2005), 6.1 (Alsema and van Wild-Scholten, 2005) and 125 kg CO₂eq/kWp (Bizzarri and Morini, 2007), respectively. On this basis the greenhouse gas emitted to produce and install the systems were estimated to be 6,899,342 kg for the fixed system and 5,040,097 kg for the tracking system. GPBT of the systems, the ratio of the calculated embodied greenhouse gas emissions and the calculated greenhouse gas savings, were calculated to be 5.203 and 2.658 years, respectively.
4. Discussion
In this paper, a fixed and a sun tracking PV energy system is designed to meet the primitive energy demands of a typical house in Sakarya, Turkey. Table V gives the cost of each unit and the total cost of the systems.

As can be seen from Table V, the setup cost of tracking systems is higher. Besides that the development stage is more complicated and regular maintenance is required for the stability of tracking mechanisms (AL-Rousan et al., 2018).

The world scientists agree that there is a strong correlation between the temperature of our planet and the concentrations of greenhouse gases in the atmosphere which still cannot be identified entirely. One of the strongest claims of this correlation is that over the last 260 years, the concentration of CO₂ has risen from 280 parts per million by volume (ppmv) to current levels of 380 ppmv and the temperature has risen by 0.5-0.8 K (Tuckett, 2009). At this point, it is possible to make significant reductions with small-scale lifestyle changes of many of the countries in the world, especially developing countries.

In Turkey, PV energy system applications are mostly fixed and the PV modules are tilted at generally accepted angles. PV energy is clean without greenhouse gas emission during the operation. However, significant emissions occur in the life cycle of PV modules until the installation is completed. Therefore, reducing the number of PV modules makes great differences in the GPBT of PV energy systems. The comparisons between the GPBT results of the optimally tilted fixed system (5.203 years) and tracking system (2.658 years) agree with this since the tracking system promises 2,545 more years without CO₂ emission. Putting away the economic benefits, sun tracking PV energy systems should be reasons of preferences in appropriate cases in a world with such an urgent climate issue.

5. Conclusions
In this paper, the investigation of PV energy utilization in electricity generation in a typical house in Sakarya, Turkey was carried out to establish its environmental impact in terms of EPBT and GPBT. For this purpose two systems were designed: an optimally tilted fixed PV energy system and a two-axis sun tracking PV energy system. The main results are given as follows:

- The total solar radiation based calculations showed that 7 PV modules in the fixed system and 5 PV modules for the tracking system were required to meet the energy demand of the related house.
- The EPBT of the fixed system and tracking system were established to be 4.43 and 3.09 years.
- The GPBT of the fixed system and tracking system were established to be 5.203 and 2.658 years.

From these results, it can be concluded that EPBT and GPBT calculation of an energy system is a vital step to determine the optimum design accurately in terms of economic and environmental benefits.

<table>
<thead>
<tr>
<th>Units</th>
<th>Fixed system cost (TL)</th>
<th>Tracking system cost (TL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV module</td>
<td>3,382.5</td>
<td>2,255</td>
</tr>
<tr>
<td>Inverter</td>
<td>1,650</td>
<td>1,650</td>
</tr>
<tr>
<td>Batteries</td>
<td>15,280</td>
<td>15,280</td>
</tr>
<tr>
<td>Cabling</td>
<td>1,000</td>
<td>1,000</td>
</tr>
<tr>
<td>Tracking mechanisms</td>
<td>0.0</td>
<td>3,000</td>
</tr>
<tr>
<td>Mechanical assembly</td>
<td>2,000</td>
<td>4,000</td>
</tr>
<tr>
<td>Total cost</td>
<td>23,312.5</td>
<td>27,185.0</td>
</tr>
</tbody>
</table>

Table V. The fundamental units and cost of the systems
References


**Corresponding author**

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Building a typology of the 100 smart cities in India

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Abstract

Purpose – The Smart Cities Mission (SCM) in India is generating significant interest among researchers and policymakers globally. Cities under the SCM, irrespective of their locations, size, capacities or local needs, are heavily investing in technological solutions to improve civic conditions. The purpose of this paper is to build a typology and urban classification system of these 100 smart cities using a series of key performance indicators (KPIs) around urban development and access to public services. The paper also systematically recognises the diversity of challenges facing these cities and assess whether a generic technology-based approach is adequate to address them.

Design/methodology/approach – A two-stage statistical process is employed in this typology building exercise – first, a cluster analysis is conducted to classify the selected cities, then a multiple discriminant analysis is used to characterise each classified city.

Findings – The urban typology analysis finds that vast disparities remain across India’s urban centres, located in different geographical regions, in terms of access to social capital and physical infrastructure. The KPIs around education, health and social services emerged from the analysis as the most significant drivers in the urban typology building process. The lack of basic community infrastructure, especially in the small-to-medium-sized cities in India, exposes the shortcomings of a one-size-fits-all technocratic smart city development strategy that assumes foundational infrastructure is already in place for technology to take effect.

Originality/value – The research methodologies developed in this paper offers a novel planning approach for smart city policymakers to devise place-based smart city interventions, acknowledging diverse cultures and specific community needs.

Keywords Cluster analysis, Smart city, Urban typology

1. Introduction

The smart city concept has become topical in academic and policy discussions in recent times. While there is a range of approaches to defining a smart city, the concept generally refers to an instrumented, interconnected and intelligent city that uses information and communication technology (ICT) to sense, analyse and integrate critical information on core systems in running cities (IBM, 2008). There exists a large pool of studies on smart cities focusing on the developed countries. However, little research has been done in a developing country context, specific to urban typology with socioeconomically and culturally diverse backgrounds. Smart city policies in the global south are somewhat embracing neoliberal urban development through “Fast Policy” (Peck and Theodore, 2015) – a process through which cities are hiring global private corporations to import and execute smart solutions that are successfully implemented elsewhere. The policy-making dynamics in India, for example, have taken a dramatic turn under the recent Smart Cities Mission (SCM) aiming to retrofit 100 selected cities into smart ones. The cities were advised by the Indian government to draft smart city master plans strictly under four months in the first phase of the nation-wide smart city challenge. More significantly, a condition was pushed on the cities that they should engage private corporations for developing the proposals. An analysis of the smart city plans by the Housing and Land Rights Network (2017) show that they are essentially an accumulation of “hot” policy ideas loaded with digital technology. Such policies that are designed at a rapid pace in India, Roy and Chatterji (2017) argue, are conceived through the corporate lenses and is a part of the urban policy transfer boom from the global north to south.

The authors acknowledge the Faculty of Built Environment, UNSW for supporting this research through a PhD Publication Award in 2019.
The impact of the technology corporations in the shaping of smart city rhetoric is such that more than 83 Indian cities have started developing command and control centres over the last one year. The control centres are the poster boy of IBM, originally conceived and executed at the Brazilian city of Rio de Janeiro to monitor urban systems using data and visualisation streamed through giant virtual screens installed under one roof (Kitchin et al., 2016). A substantial number of cities are also investing heavily in smart technologies for urban transport, including parking, traffic management, operations, where a range of global businesses is offering ready-to-install solutions (Praharaj and Han, 2019). However, a meagre five projects for education and health sector have found a place in the proposals by the 33 cities that received funding at the initial stages of the SCM (GoI, 2018). The focus of these group of cities on community infrastructure development was also shallow with two projects identified across the 33 plans. Highlighting the trends of India’s smart cities planning, a recent report by Brookings India (Ravi et al., 2016) warned that installing digital technologies alone will not improve the urban conditions in the country. The research finds that instead of looking for solutions within, the smart city plans have recognised projects that are importable, quick to execute and provides high visibility and marketing opportunities. Several studies have also argued that India’s SCM proposed a one-size-fits-all model of high-tech urbanism where local context, identities and needs are superfluous (Praharaj et al., 2018a, b, c; Seetharam, 2018).

This paper questions the fast policy-making processes and the importation of solutions without objective interrogation of the local conditions in Indian cities. We examine the top-down approach to the Indian smart city development and assess whether the predominant emphasis on command and control centres is justified. The study aims to build a new typology of advantages and disparities across 100 cities under the SCM in India. Many studies (Hill et al., 1998; Baum et al., 2006) have previously used an urban typology approach to empirically classify cities based on socioeconomic performance indicators. Such categorisation elucidates the complex structures of urban systems and supports the selection of areas for optimisation and development. Our research selects locally adapted key performance indicators (KPIs) (Praharaj et al., 2018a) to reveal the patterns of distribution of services and infrastructure and eventually determine the potential areas for optimisation under the SCM. The methodology developed in this paper holds valuable lessons for governments, especially in the global south which are looking to lay down smart city policies affecting a substantial number of urban centres. Along with smart cities, the paper contributes to the field of urban typology for the benefit of researchers and academics who are interested in indicator-based urban strategies.

2. Literature review
2.1 Urban typology research: conceptual foundations
A substantial level of empirical work on urban and areal studies has focussed on typology building that in general seeks to classify urban places according to their characteristics (Baum et al., 2006; Jones and Jones, 1970; Mikelbank, 2004). Classification of cities is, in essence, a simplification whereby a large volume of data on a set of observations is analysed to identify patterns (Mikelbank, 2004). Emerging from the need to understand and simplify complex information and processes in cities, the use of typologies provides a framework that allows identification of similarities and differences among cities. It supports a greater understanding of the processes that lead to variations among groups or clusters of cities in terms of their socioeconomic performance (Baum et al., 2006). It is the ability to elucidate the complex structure of cities and regions that make typology building exercise useful.

Urban typology building techniques have been adopted in several studies with diverse sets of interests and outcomes. Previously, urban typology based on city size – in terms of population, spatial expansion (Hill et al., 1998), economic function (Clark and Roche, 1984), socioeconomic characteristics (Mikelbank, 2004; Baum et al., 2006) and knowledge and infrastructure...
distribution (Giffinger and Pichler-Milanović, 2007; van Winden et al., 2007) is performed. However, the urban typology as a technique is yet to be applied to develop an indicator-based urban classification system in a smart city context. This paper in a novel way applies the urban typology framework on both socioeconomic and sustainable smart city indicators. By doing so, it aims to establish an evidence-based process for smart city policy decision making.

2.2 Techniques for building urban typologies
The objective of typology development is to cluster indicator data into groups having homogenous characteristics and simultaneously provide an understanding of how the groups differ. In the literature, agglomerative hierarchical clustering and partitional clustering methods are popularly used to achieve this. While agglomerative hierarchical clustering (Hill et al., 1998) begins with the same number of clusters as there are observations (the number of cities), the multistage or partitional clustering algorithms specify an initial number of groups (Orfield, 2011). Our research applies the agglomerative hierarchical clustering technique for building urban typologies to avoid the bias inherent in defining the number of clusters in advance.

While cluster analysis identifies the distinct groups within observations, it falls short in providing reasons for why those groups differ from each other. Researchers use discriminant analysis to determine the factors that drive clustering outcomes, supporting meaningful interpretations from urban typology analysis. Researchers either use the stepwise discriminant analysis and resultant discriminant scores (Hill et al., 1998) or visual data interpretation methods (Baum et al., 2006) to assess the validity of clusters and recognise critical factors. We have used discriminant scores in this research to label the clusters, avoiding the use of researcher judgement that is inherent in the other method. We did not assume as to which of the Indian cities are leading, or are distressed; instead, we have used the discriminant functions to characterise the differences among the clusters of cities.

3. Research methodology and data
3.1 Conceptual framework
This research aims to generate clusters that differentiate cities based on KPIs across a range of service domains to identify opportunities and vulnerabilities. We define opportunity in cities by their high level of efficiency in infrastructure service delivery, robust economic growth and social cohesiveness, all of which provide an ideal atmosphere for both social and technology-based innovation (Kourtit and Nijkamp, 2012; Nam and Pardo, 2011). Conversely, we associate vulnerability with cities that are exposed to risks due to substandard infrastructure and lack of health facilities, training and higher education. We hypothesise that cities of opportunity possess a high level of readiness and potential to transform themselves into smart cities in comparison to cities facing severe vulnerabilities.

As shown in Figure 1, the relative positions of city clusters on a two-dimensional plane indicate their readiness to become smart cities. These clusters are separated based on a discriminant function (referred to as discriminant score in Sections 2.2) produced as a result of the inter-city variation in KPIs. However, the concepts of opportunity and vulnerability in this study are not binary opposites. Instead, the analysis seeks to locate cities along a continuum where high vulnerability and high opportunity are considered extremes. The aim is to develop a framework that can measure the current capacities of cities to become smart cities and create a basis for continuous examination of the critical factors that drive the performance outcomes across city groups and, ultimately, help cities adjust their future policies.

3.2 Data and variables
The approach for the selection of variables presented in this paper synthesises the global measures of smart cities with the local socioeconomic and urban quality of life indicators.
First, we reviewed the global smart city indicator frameworks developed by Giffinger and Pichler-Milanović (2007), ISO 37120 (2014) and Cohen (2014) to integrated KPIs that are extensively cited in the literature and have a global appeal. In the second stage of the review, we referred the Government of India (GoI) sponsored Liveability Standards in Cities (GoI, 2016) that presents a number of locally appropriate city performance indicators around social cohesion and behaviour and lifestyle. Such an inclusive approach to defining the indicators enhances the robustness of this study, while appropriately engaging with the existing social and economic inequality in Indian cities (Kundu and Samanta, 2011).

We selected a total of 54 indicators around seven thematic domains, as shown in Table I. Nine variables were chosen under the demographic and social cohesion domain to capture social development potential. The second group of variables captures the economic trends and the supply of jobs amidst a surge in the young and working-age population in India (Chandrasekhar et al., 2006). The third set of variables are focussed on education and health capital considering a strong emphasis in the smart city literature on the bearings of clustering of knowledge institutions and a healthy workforce on creativity and urban innovation (Kourtit and Nijkamp, 2012).

In total, 13 variables were selected under the domain of physical infrastructure. As the application of ICT is defined more clearly in the areas of physical infrastructure (Caragliu et al., 2011), the analysis of variables listed here will support the identification of cities that can potentially benefit from smart technology applications. We have included the next group of three variables around digital connectivity which is considered as the backbone of a smart city. In assessments such as this, greater access to digital infrastructure will underscore cities of opportunity.

We chose six variables around housing and lifestyle and behaviour of citizens. Indicators such as the level of open defecation or access to closed bathrooms listed in this paper have never featured before in the smart city literature. While seemingly elementary, these measures are highly relevant to environmental awareness, female safety and public behaviour – interlinked issues facing urban societies in India (Joseph, 2006;
<table>
<thead>
<tr>
<th>Thematic domains</th>
<th>Indicators</th>
<th>Source of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demography and social cohesion</td>
<td>Population density (km²)</td>
<td>Census of India 2011 (censusindia.gov.in)</td>
</tr>
<tr>
<td></td>
<td>Decadal population growth rate (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sex ratio</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Child sex ratio</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Household size</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Proportion of female workers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Literacy rate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Creative and agile population (15–44-year age group)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of city population living in slums</td>
<td></td>
</tr>
<tr>
<td>Economy and jobs</td>
<td>Per capita GDP</td>
<td>Govt. of India (data.gov.in)</td>
</tr>
<tr>
<td></td>
<td>Work participation rate</td>
<td>Census of India 2011 (censusindia.gov.in)</td>
</tr>
<tr>
<td></td>
<td>Working-age population</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dependent population</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Share of main workers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Share of marginal workers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Share of secondary and service sector workers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of households accessing banking services</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Per capita capital expenditure of the ULB</td>
<td>Local corporation website</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Census of India 2011 (censusindia.gov.in)</td>
</tr>
<tr>
<td>Education and health</td>
<td>Gross enrolment ratio in higher education</td>
<td>Census of India 2011 (censusindia.gov.in)</td>
</tr>
<tr>
<td></td>
<td>No. of colleges/lakh population</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No. of universities/lakh population</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No. of college graduates each year</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No. of primary schools/1,000 children (0–6 year)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No. of secondary schools/1,000 children (10–14 year)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No. of hospital beds/1,000 population</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No. of physicians/1,000 population</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Road density (km²)</td>
<td></td>
</tr>
<tr>
<td>Physical infrastructure (mobility, water and environment)</td>
<td>Mode share of public transport (%)</td>
<td>Census of India 2011 (censusindia.gov.in)</td>
</tr>
<tr>
<td></td>
<td>Average trip length (km)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of households with access to treated tap water</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of households with access to drinking water within premises</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of households with electricity connection within premises</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of households with access to latrine within premises</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of households with piped sewer connection with latrine</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of households with wastewater connected to closed drainage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of households with no wastewater drainage connection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Household-level coverage of MSW</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Efficiency of collection of MSW (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Extent of MSW recycled and recovered (%)</td>
<td>Census of India 2011 (censusindia.gov.in)</td>
</tr>
<tr>
<td>Digital communication</td>
<td>Percentage of households with fixed internet</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of households with computer/laptop</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of households using mobile phones</td>
<td></td>
</tr>
<tr>
<td>Housing and shelter</td>
<td>Percentage of households with condition of house as good</td>
<td>Census of India 2011 (censusindia.gov.in)</td>
</tr>
<tr>
<td></td>
<td>Percentage of households with permanent house structures</td>
<td></td>
</tr>
</tbody>
</table>

Table I. List of variables used in the typology analysis and their thematic domain areas

(continued)
Desai et al., 2015). Incorporation of these issues within our study is influenced by the belief that cities can only become smart when their communities have learned to learn and make environmentally conscious decisions.

4. Empirical results

4.1 Cluster analysis

As discussed in Section 2.2, our research applied agglomerative hierarchical clustering as an exploratory tool to reveal the natural groupings of the 100 cities selected for this study. Using the standard IBM SPSS statistical software (version 22.0), we have generated a dendrogram – a tree graph displaying the clustering procedure (see Figure 2). Dendrograms are supremely efficient in determining the stopping point in the clustering process. Without this method, the hierarchical clustering process would continue until all cities were combined into one large cluster, which would be an apparent failure to build an urban classification system. When performing cluster analysis using SPSS, it is essential to set specific parameters that will be used to generate the cluster solution including the distance and linkage measures. We used the Ward method (Griffith, 1997) to compute the squared Euclidean distances among observations. The analysis began with 100 clusters because this procedure considers $n$ observations as $n$ clusters by default. Subsequently, each step reduced the total number by one cluster by systematically minimising the squared Euclidean distances between cities on each of the measured variables.

In the graphical dendrogram summary of the cluster solution shown in Figure 2, cases (cities) are listed along the $y$-axis, and distances between clusters are plotted on the $x$-axis. The vertical lines within the diagram represent the grouping of clusters at various stages of the agglomeration procedure. The distances between two adjoining clusters on a scale of 0–25 are shown on the $x$-axis above the plot. The horizontal lines within the graph connect all cases that fall within one cluster, helping to determine the final number of clusters after the stopping decision is made. In Figure 2, a four-cluster solution has emerged. However, the internal differences vary considerably within clusters. The most extended horizontal lines in the graph represent the largest difference. Greater distances towards the right side of the graph before two clusters are joined, indicate more significant differences in those clusters. The results suggest that the heterogeneity of the data in Clusters 1, 2 and 4 is very high, while Clusters 3 and 4 have significant homogeneity.

4.2 Discriminant analysis

Although the cluster analysis separated the groups of cities, it could not identify the factors that primarily drove the formation of groups. A discriminant function analysis was, therefore, conducted to determine if the 54 predictors could discriminate between the four

<table>
<thead>
<tr>
<th>Thematic domains</th>
<th>Indicators</th>
<th>Source of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living and lifestyle</td>
<td>Percentage of households with condition of house as dilapidated</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of households with temporary/unclassifiable house structures</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of households residing in own houses</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of households residing in rented accommodation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of households using cleaner energy for cooking</td>
<td>Census of India 2011 (censusindia.gov.in)</td>
</tr>
<tr>
<td></td>
<td>Percentage of households using fossil fuels for cooking</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of households with bicycles</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of households with enclosed bathroom</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of households practising open defecation</td>
<td></td>
</tr>
</tbody>
</table>

Table I.

Smart cities in India
groups of Indian smart cities created by the cluster analysis. The discriminant analysis was
used as a tool to statistically determine the differences among the four city groups and the
role played by the predictors in the clustering outcomes. Discriminant functions were
estimated based on uncorrelated linear combinations of the four groups. Each function
shows a unique solution to generate a discriminant \(Z\) score that represents differences
between the groups. Discriminant scores were calculated using the following formula
adopted from the work of McLachlan (2004) and Fraley and Raftery (2003):

\[ Z_{jk} = a + W_1X_{1k} + W_2X_{2k} + \ldots + W_nX_{nk}, \]

where \( Z_{jk} \) is the discriminant Z-score of discriminant function \( j \) for city \( k \); \( a \) is the intercept; \( W_i \) is the discriminant coefficient for independent variable \( I \); and \( X_{ik} \) is the independent variable \( i \) for city \( k \).

The discriminant analysis enumerated in Table II generated three discriminant functions and the overall function prediction was significant at \( X^2 = 443.370, p < 0.001 \), which shows that the three functions adequately explain inter-group differences. The three discriminant functions show that Function 1 contributes to 52.8 per cent of the total variance explained by the solution, while Function 2 explains 31.9 per cent. Cumulatively, 84.7 per cent of the variance was explained by Functions 1 and 2, leaving only 15.3 per cent of variance to be explained by Function 3.

The structure matrix presented in Table III computes the correlation between the predictors and discriminant functions ordered by size (factor loading). Generally, loadings of over 0.10 on the first two functions (representing the most substantial absolute correlations associated with each discriminant function) were used to draw interpretations. This is purely due to the satisfactory variance explanations by Functions 1 and 2 and the necessity to identify and interpret the factors with high loadings that appear to influence the clustering process. In Function 1, parameters related to social infrastructure emerged as key predictors. The indicators that show significant loadings above 0.10 are number of universities per lakh population, number of college graduates per year, number of hospital beds per thousand population, number of physicians per thousand population, percentage of city population living in slums and percentage of households connected to banking services. As Function 1 explains more than half of the total variance in the data set, these indicators very clearly had the maximum influence in discriminating the groups. In Function 2, the discriminating factor was the level of access to physical and digital infrastructure across cities. Within the physical infrastructure delivery domain, access to sewage, stormwater drainage, public transport, sanitation and solid waste management facilities had significant loadings as predictors. Access to fixed internet and the use of laptop/computer also contributed significantly to the clustering outcomes.

Once the different clusters of cities, the number of functions and the factors that forced their segregation had been identified, the bearing of each function on the individual and group of cities was examined. Figure 3 plots the discriminant score for each city over discriminant Functions 1 and 2. The centroids of the discriminant scores for all the cities within each group are also shown. The diagram shows that Function 1 predicted by social infrastructure significantly discriminates the group of cities in Cluster 1 from their peers in other clusters; Function 2 separates the group of cities in Cluster 2 from the others. Urban centres that form Clusters 3 and 4 are reasonably close to each other but somewhat differentiated by Function 2 (access to physical and digital infrastructure).

5. Discussion
The emerging urban typologies across the 100 smart cities in India highlight the different levels of capacity across urban centres to deliver social services and physical infrastructure.

<table>
<thead>
<tr>
<th>Function</th>
<th>Eigenvalue</th>
<th>% of variance</th>
<th>Cumulative %</th>
<th>Canonical correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13.972(^a)</td>
<td>52.8</td>
<td>52.8</td>
<td>0.966</td>
</tr>
<tr>
<td>2</td>
<td>8.433(^a)</td>
<td>31.9</td>
<td>84.7</td>
<td>0.946</td>
</tr>
<tr>
<td>3</td>
<td>4.042(^a)</td>
<td>15.3</td>
<td>100.0</td>
<td>0.886</td>
</tr>
</tbody>
</table>

Note: \(^a\)The first three canonical discriminant functions were used in the analysis.
<table>
<thead>
<tr>
<th>Function</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of households using mobile phones</td>
<td>0.236*</td>
<td>0.123</td>
<td>0.195</td>
</tr>
<tr>
<td>No. of college graduates each year</td>
<td>0.180*</td>
<td>0.127</td>
<td>0.095</td>
</tr>
<tr>
<td>Percentage of households with bicycles</td>
<td>0.174*</td>
<td>0.057</td>
<td>0.086</td>
</tr>
<tr>
<td>Percentage of households accessing banking services</td>
<td>0.158*</td>
<td>0.070</td>
<td>0.156</td>
</tr>
<tr>
<td>Percentage of city population living in slums</td>
<td>0.122*</td>
<td>0.058</td>
<td>0.042</td>
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<td>No. of physicians/1,000 population</td>
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<td>No. of hospital beds/1,000 population</td>
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<td>No. of university/lakh population</td>
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<td>No. of primary schools/1,000 children (0–6 year)</td>
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<td>Population density (km²)</td>
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<tr>
<td>Percentage of households with latrine within premises</td>
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<tr>
<td>Decadal population growth rate in percentage</td>
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Table III. Structure matrix highlighting the factor loadings.
The location of cities and their respective cluster groups are mapped in Figure 4 to provide a unique insight into the emerging urban typologies across India. This section characterises each group based on the cluster and discriminant analysis results and discusses the reasons behind the vast diversity in performance outcomes across cities and clusters.

5.1 Cluster 1 – edge cities
The analysis reveals that the 13 cities in Cluster 1 are the most “vulnerable” with limited access to both social and physical infrastructure, leading to their separation from other groups. A bulk of these are located in the mountainous North-Eastern States (Shilling, Aizawl, Kohima, Imphal and Namchi) where the rates of economic growth and public investment have remained much below the national average (World Bank, 2007). Four cities in this cluster (Port Blair, Silvassa, Diu and Kavaratti), are in the Union Territories (UT) where urban local bodies lack adequate capacities (HPEC, 2011; Ahluwalia, 2017). The analysis in this paper shows that the cities in the UTs are especially struggling with the provision of higher education and health facilities. Notably, these “vulnerable cities” have the smallest population size among the 100 cities selected for this study, with an average population of below 50,000.

We characterise these centres as “edge cities” where basic infrastructure is a far-off reality. These towns, as Sircar (2018) says, demonstrate a model of “subaltern urbanisation” – a process of autonomous growth of settlements that are generated by local market forces, and that are often unrecognised in the planning system due to their lack of political and economic influence in comparison to the mega cities in India. While these cities show a deficiency in traditional services, a bulk of investment is allocated for digital technology application under the SCM. Such diversion of funds from public welfare services (e.g. education and health) to ICT can further damage future prosperity in India’s small, resource-scarce towns and cities. From a theoretical perspective, these trends challenge the imaginings of the smart city as a universal polemic that takes for granted that infrastructure is already in place for ICT to take effect (Söderström et al., 2014). Such presumptions fail to consider the context of small, disadvantaged urban areas, especially in the global south where lack of services and splintered infrastructure is the norm.
5.2 Cluster 2 – leading cities

A total of 42 cities congregated in Cluster 2 which demonstrate superior performance in the delivery of physical and digital infrastructure. Many in this group are state capitals and mega cities (e.g. Mumbai, Delhi, Chennai and Jaipur) that appear to have driven the clustering result. These cities benefited substantially from successive GoI sponsored urban development programmes aiming to elevate these cities as the country’s growth engines (Kundu, 2014). Also in this cluster are planned towns, such as Chandigarh, Gandhinagar, New Town Kolkata, Ghaziabad, Navi Mumbai and Bidhannagar, which exhibit globally competitive modern infrastructure (Wang et al., 2010; Nirmal, 2014). A few medium-sized cities also make the cut into this elite league, including Indore, Udaipur, Jalandhar, Belagavi and Tirupati which have excelled over the last decade at bridging the service delivery deficit, as corroborated by their top positioning in the smart city selection process by the GoI (2017).

This cluster invariably represents cities of opportunities, and we label them “leading cities” based on the favourable infrastructure and economy. Besides traditional physical infrastructure,
widespread penetration of internet and mobile phones played a crucial role in differentiating this group of cities from the other clusters. The emerging digital inclination supported with hard infrastructure gives a competitive edge to these leading cities in the smart city endeavour.

5.3 Cluster 3 – moving cities
In total, 13 cities that form Cluster 3 are located in a defined region in South India. Ten of these are in the State of Tamilnadu (Tiruchirappalli, Tirunelveli, Dindigul, Thanjavur, Tiruppur, Salem, Vellore, Coimbatore, Erode and Thoothukudi). This pattern, along with that seen for the north–east region in Cluster 1, signals that cities located in the same region and with shared political environment tend to cluster together. A strikingly similar tendency of clustering was observed by Hill et al. (1998) who found that regional patterns of socioeconomic development in the USA force geographically proximate centres to perform similarly.

The analysis here shows that these cities provide a satisfactory level of social infrastructure. However, they are yet to achieve a desirable level of physical and digital infrastructure, which has led to the separation of this group from the “leading cities” cluster. What is interesting though is that some of these cities show an upward trend (see Figure 3), towards breaking into the top-performing cities group. This movement towards a positive outcome should be seen as an indication that these cities are well on course to emerge as the next-generation leaders among Indian cities if the pace of infrastructure development is moderately augmented. Hence, this research designates this group as “moving cities”.

5.4 Cluster 4 – reluctant cities
One-third of the cities under investigation is in Cluster 4. These cities are primarily from the states disreputably named as “BIMARU”, an acronym commonly used to describe the “backwardness” of eastern and central states in India (Bose, 1988). In total, 27 out of the 31 cities in Cluster 4 are in this region, performing much below the national average on most KPIs. Again, the findings for this group reiterate that cities located in the same region are naturally inclined to cluster together.

Most of the cities in this group have a medium population size; they experience economic decay, policy inadequacies and outflow of creative capital to large cities (Datta, 2007). The problems associated with the lack of access to higher education and health-related services are severe in these urban areas. These cities are characterised by the presence of powerful, yet unaccountable semi-state agencies that primarily manage urban transport, water supply and sanitation-related vital functions, leaving the democratically elected local government disempowered (Kundu, 2014; Prabaraj et al., 2018a, b). We define them as “reluctant cities” because of their lack of capacity to influence change in the infrastructure delivery and governance processes.

6. Conclusion
The global discourse on smart cities has attracted increasing interest, causing a rapid proliferation of research over the last decade. Amidst the sweeping trends of urbanisation and growing complexities of urban issues, public authorities, planners and researchers require novel methods to understand cities and identify the opportunities for developing smart solutions. This study built urban typologies across 100 cities in India using KPIs to demonstrate their level of readiness to become smart cities. We divided the cities functions into indicators and quantified them through data to reveal the status and trends in urban performance and the health and metabolism of cities. Our concern was not to measure how smart Indian cities are at present. Instead, we emphasised on the identification of key factors and policy areas that need attention across the differently capacitated regions to enable the smart transformation of cities. Deviating from the conventional ranking practices, we developed a typology of cities based on
agglomerative hierarchical cluster analysis. Discriminant analysis in this study determined the critical factors influencing India’s urban prosperity. The research has revealed that poor distribution of – and access to – social services (higher education, health, etc.) severely hinders progress in India’s small and medium-sized towns. Simultaneously, the lack of necessary infrastructures, such as stormwater drainage and sanitation challenges disadvantaged cities to provide a reasonable level of quality of life for their citizens. It is ironic that while the smart cities proposals are looking to import and execute hot technology solutions and shape high-tech urban precincts, the real need rests with soft issues around socially equitable development, knowledge and health capital. The significant differences in the performance outcomes and existing capacities between the megacities and the small towns highlight severe flaws in the fast policy-making process (Peck and Theodore, 2015) that encourages one-size-fits-all development models. The findings from this study demonstrate that socially inclusive, knowledge-based development (Yigitcanlar et al., 2008) should be a priority for the Indian small and medium towns selected under the smart cities initiative. The ambitious development of ICT-driven smart city control centres or the deployment of smart sensor is without a basis while the underlying infrastructure and human development is a far-off reality in these cities. On the contrary, the megacities and planned towns which enjoy a satisfactory level of social, physical and digital infrastructure can potentially use digital technology to enhance the efficiency and reliability of services. This paper adds to the scholarly debates in two aspects. First, we provide a rigorous set of evidence about the link between socioeconomic performance and the evolution of cities to become smart. Previously, urban typology researchers have used data on urban characteristics to classify cities (Hill et al., 1998; Mikellidou, 2004; Baum et al., 2006). On the other hand, academic works on smart cities have relied on indicator data to rank urban areas (Giffinger and Pichler-Milanovic, 2007; Cohen, 2014). Our research presents a synthesis of the two by developing a first-of-its-kind urban typology using socioeconomic and smart city indicators. Second, our findings contribute to urban and regional studies by revealing the tendency of cities located in the same region to cluster together. Such trends indicate that regional political processes and cultural factors, to a great extent, determine how cities perform. We hence argue for a place-based approach for identifying smart city emphasis areas that take into account the locational advantages, disparities and unique cultural characteristics. In terms of contributions to policy, our research provides a guideline for national or regional policymakers who are leading a vast number of smart city projects, to characterise each city and select the intervention areas systematically. In countries, such as China, Australia or at a continental scale (e.g. Europe), urban typology-based smart city policy development approach shows significant promise.

References


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Exploring firm performance by institutional pressures driven green supply chain management practices

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Abstract
Purpose – Environmental concerns are rapidly increasing in the industries across the world. They are a more serious issue, especially, in the developing countries due to the prevalence of old practices and outdated technology. The purpose of this paper is to understand the role of institutional pressure and environmental orientation of the firm in adopting green supply chain management (GSCM) practices, and thereon the effect of GSCM on the firm’s performance.

Design/methodology/approach – By employing survey methodology using purposive sampling technique, the data were collected from 229 respondents who were working as supply chain management professionals in various manufacturing firms. The hypotheses were tested through partial least square structural equation modeling (PLS-SEM).

Findings – The findings reveal that both institutional pressures and environmental orientation significantly impact GSCM practices. The result further shows that GSCM practices have a positive effect on the environmental and economic performance as well as customer effectiveness.

Originality/value – Industries in the developing economies like Pakistan are reluctant to implement GSCM practices due to the perception of ambiguous financial implications. This study signifies that institutional pressures act as an effective driving force for change management and compliance.

Keywords Green supply chain management, Environmental performance, Economic performance, Environmental orientation, Institutional pressure, Customer effectiveness

Paper type Research paper

1. Introduction
Supply chain management is considered an important factor in environmental management (e.g. Wu and Dunn, 1995; Florida, 1996; Min and Galle, 1997). The recent years have witnessed a substantial shift in the use of organizational strategies for enhancing the social and environmental performance of organizations (Hart and Milstein, 2003). Due to the increased environmental awareness, organizations are increasingly inclined toward adopting the green supply chain management (GSCM), which is a process in which products or services are sourced, produced and delivered by eco-friendly processes in order to fulfil the stakeholders’ concerns (Ahmed et al., 2018). Moreover, studies on GSCM recommend that the authorities and decision makers need to considerably improve efficiency and effectiveness of their work (Chen and Lu, 2016).
Recent research has found that the environment-friendly practices enhance organizations’ efficiency and increase their profits by reducing the wastage (Khan et al., 2019).

GSCM is evolving as the new managerial philosophy that organizations can adopt to attain their economic objectives by reducing their effects on environment and improving their environmental efficiency (Van Hoek, 1999). Moreover, greening the supply chain and operations increases competitive and cooperative advantages, leading to increased competitiveness and economic performance (Rao and Holt, 2005; Choi and Hwang, 2015). Several studies have highlighted the potential advantages of GSCM, such as enhancement of perceived reputation of organizations, increasing efficiency and effectiveness, process differentiation and revenue growth, to motivate managers for its adoption (Rao and Holt, 2005; Wu and Pagell, 2011; Golicic and Smith, 2013). Therefore, to maintain equilibrium between both economic and environmental performance, the managerial approach of GSCM needs to be developed and adopted (Felice et al., 2013). Moreover, key factors that have been leading the integration of environmental management and sustainability are compliance with rules and regulations, and legislation (Green et al., 2012). Companies need to develop their capabilities to manage and control the environmental performance of their operations to tackle strict institutional protocols along with an increase in customer demand. The impact of institutional pressures can be a driving factor to bring behavioral shift in the focal firm to become socially responsible by adopting GSCM practices in order to meet environmental objectives (Ciliberti et al., 2011).

Zhu et al. (2012) stated that GSCM is still a new idea in many manufacturing industries. Recent studies in this area have revealed that most of the businesses in developing Asian countries will face serious environmental issues in the next couple of decades due to environmental degradation and scarcity of resources (Zhu et al., 2005; Shipeng and Linna, 2011; Wu et al., 2011; Diabat and Govindan, 2011; Zhu et al., 2012). According to US Census Bureau, Pakistan is the sixth most densely populated country in the world (www.census.gov). Water scarcity and environmental degradation are some of the major concerns in this region (Khan et al., 2019). Developing countries have to change and design their supply chain to make it environment friendly (Mudgal et al., 2009). Industries, especially in Pakistan, are reluctant to implement green chain management practices due to the perception of negative financial implications (Ahmed et al., 2018), which hinders their self-motivated adoption of green practices. Institutional pressure, therefore, acts as an effective driving force for change management and compliance in such scenarios.

The results of the past studies specially conducted in the context of developing countries to explore the influence of green practices on various performances outcomes of the organizations, have reported mixed outcomes (Vijayvargy et al., 2017; Ahmed et al., 2018; Wu et al., 2015; Zhu et al., 2013; Zhu and Sarkis, 2006). These studies also reflect that organizations sometimes consider the implementation of GSCM practices to be a burden on their limited resources (Ahmed et al., 2018). GSCM activities performed by an organization are considered crucial for the improvement of organizational performance (Zailani et al., 2012). Moreover, flexibility of resources and redundancies help a firm’s operations in building up customer effectiveness by increasing agility and adaptability (Ahmed et al., 2019), but GSCM practices are more effective in making the process leaner and waste free (Mumtaz et al., 2018). According to Teixeira et al. (2016), GSCM has started to be considered as an important management tool in the recent years, but its implementation and execution remain a problem mostly in developing countries, owing to the lack of motivation and understanding on the part of managers and administrators. Industrialists and investors feel that implementation of GSCM practices has no significant impact on engaging customers. In addition, the research conducted in the developing countries has found GSCM to have an ambiguous effect on various performance outcomes (Teixeira et al., 2016; Geng et al., 2017; Ahmed et al., 2018).
Some research works on the subject of green supply chain have found significant impact of GSCM practices on the economic and environmental outcomes of the organizations (Golicic and Smith, 2013). However, financial benefits or cost–benefit trade-offs related with the GSCM are still not clear in the literature. For instance, Younis et al. (2016) found that none of the GSCM practices have any significant impact on environmental performance. Similarly, the impact of green supply chain practices over economic performance is still not clear (Zhu et al., 2012). Therefore, it is highly important for the managers and practitioners to understand the driving forces for implementing GSCM practices and their subsequent effects on performance, especially in the context of a developing country like Pakistan.

Considering the conflicting results of the past studies, the objective of the current research is to investigate the role of organizations and stakeholders as motivators in the adoption and implementation of green supply chain management practices. Additionally, this study will explore the effects of implementing common practices of green supply chain on different aspects of corporate performance. The contribution of this study is multifaceted: first, it contributes to the literature on GSCM domain by evaluating the impact of GSCM on economic and environmental aspects. Second, this study provides insight into the performance outcomes by deploying GSCM practices. Third, it contributes important implications to the industry by providing guidance to the managers to develop and implement successful GSCM practices in their organizations.

Therefore, this study aims to answer primarily two research questions:

**RQ1. What are the driving forces in the implementation of GSCM practices in a firm?**

**RQ2. What is the impact of GSCM practices on various dimensions of firm performance?**

The rest of the research paper is organized in the following sections: Section 2 deals with review of the relevant past studies and hypotheses development, Sections 3 and 4 include methodology and data analysis, whereas the final section contains discussion, conclusion and managerial implications.

### 2. Literature review

#### 2.1 Theoretical background

The research model in the current study is based on two theories: the resource-based theory (RBT) and the institutional theory. The RBT gives the basis for identifying organizational orientations toward the environment, which set supply chain relationships with environmental responsibility and GSCM practices as a strategic step to create value (Hart and Dowell, 2011). Moreover, the RBT states that firms compete in the market on the basis of unique strategic capabilities, and it is assumed that differences in the capabilities of the competing firms help in maintaining differences in performance (Choi et al., 2018; Kirchoff et al., 2016; Barney, 1991; Sirmon et al., 2007). GSCM is an advantage that cannot be easily nullified, and it is considered to be a valuable asset for any organization (Barney, 1986; Guang Shi et al., 2012; Choi et al., 2018). However, it is an intangible advantage, so it is difficult to be replicated (Chan et al., 2012).

Firms tend to take initiatives that can make them acceptable in the society. Consequently, the adoption of some organizational policies may increase a firm’s legitimacy to be operated by the external factors and/or stakeholders. Therefore, institutional theory that deals with pressures on the organizations to adopt environment-friendly practices is used in the current study (Agarwal et al., 2018). According to this theory, environmental configuration is influenced by three factors: normative pressure, coercive pressure and mimetic pressure (DiMaggio and Powell, 1983). The normative pressure deals with external pressure of customers, suppliers and similar forces that have invested their interest in the organization (Yang, 2018). The coercive pressure is exerted by powerful entities such as
government authorities (Rivera, 2004; Agarwal et al., 2018), whereas mimetic pressure is the one that a firm takes from its competitors (Saeed et al., 2018), such as the pressure to adopt the best practices from the organizations that are working in the same industry.

2.2 Green supply chain management

There are several definitions of GSCM available in the literature. In the current study, GSCM is defined as a strategic capability that contains strategies, practices, and policies that will concentrate on managing the environmental impact of supply chain operations (Rauer and Kaufmann, 2015).

2.3 Hypotheses development

2.3.1 Environmental orientation. “Recognition by a manager about the importance of environmental issues faced by their firms” is defined as environmental orientation (Banerjee et al., 2003, p. 106). Environment-oriented firms reduce the environmental impact through proactively driven reconfiguration in their business practices (Menon and Menon, 1997). Environmental orientation can be divided into two dimensions of “internal orientation and external orientation” (Banerjee, 2002). An internal environmental orientation is defined as intra-organizational learning, knowledge sharing and environmental responsibilities among organizational members (Chan et al., 2012), whereas an external environmental orientation deals with legitimizing a firm’s activities to stakeholders by combining its green practices in order to achieve firm’s financial performance objectives (Banerjee et al., 2003; Fraj-Andrés et al., 2009). However, an organization needs to manage complex and changing business environment to develop successful green supply chain practices. In this regard, environmental orientation helps managers to develop processes that are considered socially complex, innovative and strategically valuable (Russo and Fouts, 1997; Gabler et al., 2015). Having an environmental orientation provides strategic support within the organization for implementing green supply chain practices (Kirchoff et al., 2016). Furthermore, it has been reported that aforementioned two dimensions of environmental orientation have a positive impact on corporate green supply chain practices (Chan et al., 2012). Thus, it is hypothesized that internal and external orientations have a significant impact on organizational GSCM practices:

H1. The environmental orientation as strategic capabilities directly and positively influences the GSCM practices.

2.3.2 Institutional pressures. Institutional theory’s three institutional isomorphic pressures, namely coercive, normative and mimetic pressures, can affect an organization’s competitive environmental position (DiMaggio and Powell, 1983; Sarkis et al., 2011). Environmental management practices can be driven by coercive pressure, which is an important factor among manufacturers in developing countries. Managers of manufacturing firms receive the coercive pressures from regulatory authorities for the implementation of green supply chain practices in pursuance of improved performance (Agarwal et al., 2018). Implementing GSCM practices is a core normative pressure from customers and the market because of their increasing environmental expectations from manufactures (Yang, 2018). Especially, exports and foreign sales directly pressurize the organizations to adopt and implement green supply chain practices in order to meet their customers’ terms and conditions (Christmann and Taylor, 2001; Lai et al., 2012). However, following a market trend and/or benchmarking the market competitors also help in excelling in operational and manufacturing domain (Saeed et al., 2018).

Lai et al. (2011) stated aforementioned pressures as motivators for green practices. On the contrary, due to the depletion of resources and degradation of human health and
environment, manufacturers are regularly being pressurized from end consumers and
governments to implement green practices (Vanalle et al., 2017). However, literature has
contrasting evidence with reference to the presence of these pressures. For instance, Lin and
Ho (2011) reported the presence of regulatory pressure for the adoption of green logistics on
the service providers; however, they questioned the presence of customer pressure.
As theoretically discussed, institutional pressure should have an impact on GSCM practices.
Therefore, the following is hypothesized:

**H2.** The institutional pressure has a direct and positive impact on green supply
chain practices.

2.3.3 Customer effectiveness. Customer effectiveness refers to efficiently meeting customer
demand for improved customer loyalty and long-term relationships (Clifford Defee and
Stank, 2005; Carter and Rogers, 2008; Johnson and Templar, 2011). Customer effectiveness is
mainly concerned with customer satisfaction (Mentzer et al., 2001; Fugate et al., 2010). GSCM
practices improve customer effectiveness through continuous product availability that
meets specific environmental criteria, order fulfillment and high level of customer services
(Golicic and Smith, 2013). Customers are getting more concerned with respect to possible
damage caused to environment (Najmi et al., 2019), and they are urging manufacturers to
align their manufacturing operations as per GSCM (Vanalle et al., 2017). Although
customers consider GSCM as a competitive factor among manufacturers, but there is a
possibility that in order to be environment friendly, manufactures may have adverse
effects on customer effectiveness (Ahmed et al., 2018). According to Kirchoff et al. (2016),
improvement through environmental quality management, customer and vendor
coordination on environmental products and manufacturing processes, and designing
and redesigning of products are the factors associated with customer effectiveness.
Therefore, the following is hypothesized:

**H3.** The GSCM practices positively and directly influence the customer effectiveness.

2.3.4 Economic performance. Economic performance is one of those outcomes that force an
organization to be environmentally oriented. Researchers are in agreement that in order to
avail the opportunities in a competitive environment, businesses need to address
environmental problems (Hansmann and Kroger, 2001; Wagner and Schaltegger, 2006;
Lai et al., 2010). Moreover, most of the previous research works have determined that there is
a positive relationship between an organization’s internal and external GSCM practices and
its economic performance (Gil et al., 2001; Montabon et al., 2007; Rao and Holt, 2005; Wong
et al., 2012). ISO 14001-certified companies can gain internal performance advantages by
adopting green environmental practices (Ahmed et al., 2018; Segarra-Ona et al., 2012;
found that an organization’s internal relationships can provide formal or informal
mechanisms that promote trust, reduce risk and increase innovation and profitability.
These intra-organizational relationships include cross-functional collaboration for creating
environmental awareness, promotion of optimum utilization of resources for countering
adverse effects on human health and environment, and integration for implementing
environment auditing programs (Zhu et al., 2013). Having GSCM practices will eventually
reduce the waste from the operations, which help manufacturers to achieve economies of
scale (Ahmed et al., 2018). Moreover, through GSCM, an organization will have long-term
benefits in terms of profitability and sales performance (Bowen et al., 2001). Specifically in
the context of developing countries, it helps to explore new business avenues and enhances
a manufacturer’s competitive capabilities (Esfahbodi et al., 2016). It also increases a firm’s
efficiency by improving energy consumption, reducing operations waste, optimizing
material purchases and countering manufacturing waste (Zailani et al., 2012). Furthermore, GSCM practices are directly associated with economic performance (Zhu et al., 2013; Vanalle et al., 2017). Thus, the following is hypothesized:

H4. The GSCM practices have a significant influence on economic performance.

2.3.5 Environmental performance. According to some scholars, environmental performance is seen as the means to the twin goals of accessing economic and environmental sustainability, which improves and maintains life style of people without damaging environmental resources (Yusuf et al., 2013). Changes in the production process of products and services in order to decrease effects on environment for better life quality result in improvement of environmental performance (Honkasalo et al., 2005). The sustainability of green supply chain practices is imperative for environmental and social benefits (Carter and Rogers, 2008; Hutchins and Sutherland, 2008; Govindan, 2015). Environmental performance outcome consists of environmental risk reduction, corporate image improvement and contribution to environmental protection. An organization can increase environmental performance through adopting green production practices within its production process (Halme, 2002). Therefore, the following is hypothesized:

H5. The GSCM practices positively and directly influence the organizational environmental performance.

2.4 Conceptual model
As per the aforementioned discussion, the proposed conceptual model is presented in Figure 1.

3. Research methods
The current study adopted quantitative research approach that provides the advantage of producing a more general picture of a population through sampling and the use of statistical techniques (Kelle, 2006). The survey methodology was adopted wherein a self-administered questionnaire was used to collect data from the respondents.
3.1 Measures
For the purpose of data collection, a self-administered questionnaire was developed. It was divided into two parts: the first part consisted of measuring items adapted from previous research works, whereas the second part consisted of questions related to demographic details of the respondents. The details of the measuring items are summarized in Table I. The present study has two higher order constructs, namely institutional pressure (normative, coercive and mimetic pressures as first orders) and GSCM practices (eco-design, supply chain partnering and internal environment management). All measuring items were on a five-point Likert scale, ranging from 1: Strongly Disagree to 5: Strongly Agree. Prior to the data collection, the questionnaire was validated by industry and academic experts, and their suggestions were incorporated to ensure its face and content validity.

3.2 Sample
In order to meet the objective of this study, supply chain professionals and managers from ISO 14000 and ISO 14001-certified companies from Karachi, Pakistan, were selected. The purposive sampling technique was used for data collection and the respondents were assured of data protection and anonymity. During the first quarter of 2017, around 800 questionnaires were distributed, but after data screening, the final sample size of the research was of 229 respondents, with the response rate of 28 percent. The sample size of the current study met the threshold of minimum sample size based on 10 times rule method, recommended by Hair et al. (2011). In order to counter the common method biasness, the procedural guidelines as discussed by MacKenzie and Podsakoff (2012) were followed, especially at the stages of designing questionnaire and administering it to the respondents. Due to non-response bias, late respondents were considered as non-respondents as per their behavior (Saeed et al., 2018); therefore, the sample was divided into two groups of early and late respondents. Both groups' means were compared through independent t-tests, and the results were found to be insignificant at 5 percent level. This result supports the absence of non-response bias in our study.

The demographic profiles of the respondents are summarized in Table II.

4. Data analysis and results
The softwares used for the data analysis were SPSS 22 and SmartPLS 3.2.4. The gathered data were screened through SPSS to detect missing data and identify multi- and uni-variate outliers. Partial least square structural equation modeling (PLS-SEM) by using SmartPLS 3.2.4 was applied after data screening. In comparison to the conventional covariance-based

<table>
<thead>
<tr>
<th>Constructs</th>
<th>No. of items</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental orientation (EO)</td>
<td>6</td>
<td>Banerjee et al. (2003) and Fraj-Andrés et al. (2009)</td>
</tr>
<tr>
<td>Internal E-Management (IEM)</td>
<td>4</td>
<td>Zhu et al. (2008) and Bowen et al. (2001)</td>
</tr>
<tr>
<td>Eco-design (GED)</td>
<td>4</td>
<td>Zhu and Sarkis (2004), Zhu et al. (2008), and Melnyk et al. (2003)</td>
</tr>
<tr>
<td>Institutional pressure – Coercive (IPC)</td>
<td>3</td>
<td>Zhu et al. (2013)</td>
</tr>
<tr>
<td>Institutional pressure – Normative (IPN)</td>
<td>4</td>
<td>Zhu et al. (2013)</td>
</tr>
<tr>
<td>Institutional pressure – Mimetic (IPM)</td>
<td>3</td>
<td>Zhu et al. (2013)</td>
</tr>
<tr>
<td>Economic performance (EP)</td>
<td>4</td>
<td>Zhu et al. (2013)</td>
</tr>
<tr>
<td>Environmental performance (ENP)</td>
<td>4</td>
<td>Zhu et al. (2013)</td>
</tr>
<tr>
<td>Customer Effectiveness (CE)</td>
<td>2</td>
<td>Fugate et al. (2010) and Min et al. (2007)</td>
</tr>
</tbody>
</table>

Table I. Details of measures
structural equation modeling (CB-SEM), PLS-SEM has the tendency to explain more variance of the data, and it is strongly recommended for testing the hypotheses in theory exploration involving complex models with relatively small sample size (Hair et al., 2017); therefore, it has been termed “Silver Bullet” (Hair et al., 2011). Many GSCM-related previous studies have also applied PLS-SEM (Ahmed et al., 2018; Saeed et al., 2018; Agarwal et al., 2018; Vanalle et al., 2017), hence justifying the robustness of this technique in the similar context. The current study adopted the two-step method, discussed by Hair et al. (2016), which includes the assessment of outer and inner models.

4.1 The measurement of the outer model

For the purpose of measuring the validity and reliability of the outer model, content validity, convergent validity and discriminant validity were tested.

4.1.1 The content validity. To measure the content validity, factor loadings and cross loading were analyzed. For the strong loading of content validity, factor loading items within a construct should be greater than loading items outside the construct model (Chin, 1998; Hair et al., 2013). The factor loading items within the construct loading items that were lower than the items outside the model were removed. However, majority of the factor loadings were found to be greater than 0.7, which confirms the content validity of the outer model. Tables III and IV provide the evidence of the content validity of the proposed model.

4.1.2 The convergent validity. The collective convergence of a group that supports to achieve a level of validity toward a conceptual measurement is known as convergent validity (Hair et al., 2013). Three dimensions mutually contribute to achieve the level of convergent validity. First, factor loadings should be higher than 0.7 and need to be statistically significant (Hair et al., 2017; refer to Table III). Second, as per Fornell and Larcker (1981), the value of average variance extracted (AVE) should be more than 0.5. Third, the composite reliability must be greater than 0.7 (Hair et al., 2017) to support convergent reliability. All the convergent validity criteria are met by our model, as depicted in Table V.

4.1.3 The discriminant validity. When the set of items of a variable differentiates with the items of the other variables, discriminant validity is established. There are three measures to evaluate discriminant validity. First, the difference of the loadings of all the items within the construct and outside the construct must be greater than 0.1 (Gefen and Straub, 2005).
Second, a method advised by Fornell and Larcker (1981), a correlational matrix, which is the square root of AVE with the absolute value of the correlational of the construct in rows and columns, as shown in Table VI. According to the suggested test, the value of the diagonal of each construct (represents square roots of AVE) is higher than its own column and row (represents correlations among constructs). Third by heterotrait–monotrait ratio (HTMT) test, in which all the values of construct should be less than 0.9 (Hair et al., 2017), as mentioned in Table VII.

### 4.2 Measurement of inner model

The inner model consists of evaluating predictive relevance of the model followed by testing recommended hypotheses (Ringle et al., 2015).

#### 4.2.1 Predictive relevance of the model

The predictive power of a variable is studied through $f^2$, $R^2$ and $Q^2$. According to Cohen (1988), for the strong value of $R^2$, it should be close to 0.26 and for the weak, the value should be between 0.02 and 0.13. Predictive power can be identified if the value of $Q^2$ is greater than 0 or higher than the different between $R^2$ and $Q^2$. Table VIII represents the predictive relevance power of all constructs as per the mentioned grounds. Moreover, the effect size of the structural relationships

<table>
<thead>
<tr>
<th>Constructs</th>
<th>Items</th>
<th>Loadings</th>
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<th>$t$-statistics</th>
<th>$p$-values</th>
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<tr>
<td>CE</td>
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<tr>
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<td>0.031</td>
<td>26.667</td>
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<tr>
<td>EO</td>
<td>EO3</td>
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<td>0.050</td>
<td>13.587</td>
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<tr>
<td>EO</td>
<td>EO6</td>
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<tr>
<td>EP</td>
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<tr>
<td>EP</td>
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<tr>
<td>EP</td>
<td>EP4</td>
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<td>GED</td>
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<tr>
<td>GED</td>
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<td>6.316</td>
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<td>GED</td>
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<td>IPC</td>
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<tr>
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<td>39.065</td>
<td>0.000</td>
</tr>
<tr>
<td>IPN</td>
<td>IPN3</td>
<td>0.653</td>
<td>0.045</td>
<td>14.499</td>
<td>0.000</td>
</tr>
<tr>
<td>IPN</td>
<td>IPN4</td>
<td>0.777</td>
<td>0.033</td>
<td>23.377</td>
<td>0.000</td>
</tr>
<tr>
<td>SCP</td>
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<td>0.704</td>
<td>0.051</td>
<td>13.788</td>
<td>0.000</td>
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<tr>
<td>SCP</td>
<td>SCP2</td>
<td>0.839</td>
<td>0.027</td>
<td>30.665</td>
<td>0.000</td>
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<td>SCP</td>
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<td>SCP</td>
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<td>SCP</td>
<td>SCP6</td>
<td>0.667</td>
<td>0.064</td>
<td>10.412</td>
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<tr>
<td>ENP</td>
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<td>0.695</td>
<td>0.064</td>
<td>10.794</td>
<td>0.000</td>
</tr>
<tr>
<td>ENP</td>
<td>ENP4</td>
<td>0.942</td>
<td>0.018</td>
<td>51.047</td>
<td>0.000</td>
</tr>
</tbody>
</table>

*Source: Authors’ estimation*
can be examined through $p$-values, but these only provide significance. For effect size, Hair et al. (2017) defined the thresholds of 0.02 as weak, 0.15 as moderate and 0.35 as strong effect. The values of the effect sizes ($f^2$) are shown in Table IX.

### 4.2.2 Hypotheses testing

As per Table IX, there is a significant effect of environmental orientation on GSCM at the 0.01 level of significance ($\beta = 0.33$, $t = 4.55$, $p < 0.01$). Moreover, institutional pressure also has a significant impact on GSCM at the 0.01 level of significance ($\beta = 0.43$, $t = 6.24$, $p < 0.01$). Consequently, GSCM has a significant and positive impact on customer effectiveness at the 0.01 level of significance ($\beta = 0.32$, $t = 4.88$, $p < 0.01$). Similarly, GSCM has a positive effect on economic performance ($\beta = 0.38$, $t = 8.38$, $p < 0.01$) and environmental performance at the 0.01 level of significance. Therefore, all the proposed hypotheses from $H1$ to $H5$ were supported. The hypotheses testing results are presented in Figure 2.

### 5. Conclusion, discussion and recommendations

#### 5.1 Conclusion

This study was conducted to investigate the role of strategic environmental orientation, which is self-motivated urge to become environment friendly, and institutional pressures, which are
the influences of governmental institutions, competitors and customers, in fostering successful implementation of GSCM. It also investigated the impact of GSCM practices on performance indicators of organizations. This study is significant in the context of deteriorating environmental conditions in the sixth most populated country of the world, Pakistan.
The findings of this research reveal that both strategic orientation and institutional pressures are important to influence organizations to adopt green supply chain practices, with institutional pressure exhibiting a higher effect size. The findings further reveal that among different types of institutional pressures, normative pressure exerted by customers and supply chain partners has the highest effect, followed by mimetic and coercive pressures. Organizations that adopt GSCM practices are found to be mostly focused on building supply chain partnerships with stakeholders in order to reap maximum benefits. On the performance front, this study found very positive outcomes on triple bottom line. It was also found that GSCM practices strongly impact the environmental performance as a corporate social responsibility, which is quite beneficial for gaining customers’ attention. Moreover, GSCM practices were also found to have a significant impact on firms’ economic performance and customers’ effectiveness.

5.2 Discussion

Majority of the manufacturers in the developing countries like Pakistan try to avoid penalties imposed by the government authorities and trading organizations on account of environmental violation to avoid economic loss. This makes organizations and decision makers willing to adopt GSCM practices that can save them from such unwanted
losses (Vanalle et al., 2017). This study has further shown that institutional pressures, which include normative, mimetic and coercive pressures, force Pakistani firms to implement GSCM practices. Such firms tend to apply GSCM practices due to the institutional pressure, unlike the firms from developed countries that implement the GSCM policies mainly to uphold laws and due to media and non-governmental organizations (NGOs; Zhu et al., 2010; Zailani et al., 2012).

As environmental concerns are on the rise, the policy makers and environmentalists must exert more institutional influence on the industries in order to meet the requirements for environment-friendly practices. Moreover, internal motivation and strategic focus on environmental protection from top-bottom approach are important for effective implementation of GSCM practices (Ahmed et al., 2018). Therefore, managers and strategists must also work on their strategic environmental orientation through clear communication to all the stakeholders regarding the goals and expectations from each other to get better GSCM operations in place to get maximum benefits out of it (Kirchoff et al., 2016). Finally, this research also proves that GSCM practices can directly lead to improvement in the firm’s performance, which must be the motivating factor for all stakeholders and decision makers to adopt these practices in letter and spirit.

5.3 Recommendations
In the light of aforementioned discussion, this research provides practical implications for organizations and policy makers. It has important implications for manufacturers who can achieve improved economic performance by implementing green supply chain practices. Manufacturers need to understand the structural relationships between internal and

Note: Path coefficients and t-statistics
external aspects of implementing GSCM practices and should ensure the coordination of the firm’s activities for better environmental and operational performance. The findings also have practical implications for public policy makers and regulators who need to motivate manufacturers and managers of firms to implement green supply chain practices within their organizational activities, as mimetic and normative forces of institutional pressure have been found to be influential antecedents affecting the implementation of GSCM practices in operations. Government bodies should also promote the importance of green environment and create awareness of its benefits among the manufacturers and managers, as they have the authority to force the organizations to bring eco-friendly changes in their operations.

This study also provides guidance to managers about the prerequisites of developing and implementing successful and valuable green supply chain practices in an organization. The important role of strategic organizational orientation, such as environmental orientation, should be kept in mind to control and follow the strategic direction of GSCM practices, rather than simply responding to outer pressures. Furthermore, the significant impact of GSCM on three performance outcomes of an organization can allow managers to achieve more balanced performance. In the light of our findings, by adopting environment-friendly practices, managers can enhance both efficiency and effectiveness of their organizations in the pursuit of sustainable competitive advantages.

5.4 Future research agenda
The current study opens several avenues for future research. Due to the dynamic nature of GSCM, cross-sectional survey data can be used in future research to determine the nature of strategic changes in response to the organizational environment. A longitudinal research in future can provide insight into performance implications of GSCM that could not be investigated in a short duration in the present study. A longitudinal study in future may also disclose how managers’ attitudes toward GSCM practices are affected by the changes in regulation, corporate culture, state of the economy, stakeholder demand and the competitive position of the firm. (Bansal and Roth, 2000).

As multinational firms deal with varying regulations and network structures, the future researchers should study different geographical issues related to green supply chain practices in these firms in order to gain a more universal perspective of the linkage between environmental initiatives and supply chain performance. Furthermore, a comparative future study of green supply chain practices of firms from different regions of the world will also provide important implications, as green supply chain practices differ due to culture, economic stature and the ethical practices of a region.

Finally, future research should investigate further dimensions of performance outcomes that are related to GSCM practices. Researchers may use complete triple bottom line approach to explore the performance dimensions that focus on economic, environmental and social performance.

References


Further reading


Appendix

Environmental Orientation (EO)
- Employees in our business unit understand the importance of environmental responsibility.
- Our business unit focusses on environmental awareness in our operations.
- Environmental responsibility is important to our business unit.
- The ability of our business unit to create a positive image of environmental responsibility is important.

GSCM: Internal E-Management (IEM)
- Environmental performance metrics are used regularly by corporate management.
- Cross-functional cooperation is practiced to create environmental improvements in the supply chain.
- Environmental compliance and auditing programs in all departments are executed periodically.

GSCM: Supply Chain Partnering (SCP)
- Joint decisions with our supplier about ways to reduce overall environmental impact of our products.
- Joint decisions with our supplier about ways to reduce overall environmental impact of logistics operations.
- Cooperation with our customers to reduce the environmental impact of our products.
- Joint decisions with our customers about ways to reduce overall environmental impact of logistics operations.
- Cooperation with our customers to anticipate and/or resolve environment-related problems.

GSCM: Eco-Design (GED)
- Our business unit concentrates on design or redesign of products to reduce consumption of material and/or energy.
- Our organization focusses on design or redesign of products for recovery, reuse, recycling, and/or remanufacturing.
- We work on the design or redesign of products to avoid or reduce use of hazardous substances.
- We work hard on the design or redesign of products to reduce the overall environmental impact of the product.

Institutional pressure (IP) (Coercive)
- The green environmental management of our firm will be influenced by national environmental regulations (such as waste emission, cleaner production, etc.).
- The green environmental management of our firm will be influenced by regional environmental regulations (such as waste emissions, cleaner production, etc.).
- The green environmental management of our firm will be influenced by regional resource saving and protection regulations.
Institutional pressure (IP) (Normative)
- In order to respond to the green environmental protection tendency, our firm will consider the effect on export.
- In order to respond to the green environmental protection tendency, our firm will consider the effect on sales to foreign customers.
- In order to respond to the green environmental protection tendency, our firm will consider the effect on environmental requirements from domestic customers.
- For our firm, establishing company’s green image is extremely important.

Institutional pressure (IP) (Mimetic)
- The green environmental management of our firm will be affected by competitor’s green environmental management protection strategy.
- The green environmental management of our firm will be affected by substitution product green environmental strategy.
- The green environmental management of our firm will be affected by professional environmental protection group.

Economic performance (EP)
- Implementing green practices has improved productivity in our organization.
- Opting green practices has increased profitability in our organization.
- Green practices have helped our firm to increase market share.

Environmental Performance (ENP)
- GSCM practices have helped our firm to reduce environmental emission.
- We have improved our corporate image by applying green supply chain practices.

Customer Effectiveness (CE)
- GSCM practices help us to have a consistent stock availability.
- GSCM practices help us to handle customer emergencies (i.e. stock outs).

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Why Indian cities are so chaotic? Decoding from the urban development efforts of Chandigarh

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1. Introduction
Travelling across India invariably raises questions regarding the state of Indian cities. In spite of recent economic progress and establishment of several new towns across India, the physical and socio-economic conditions of cities have not altered much. In addition to organic cities, the newly developed towns are also showing symptoms of unplanned growth. Plans and visualisations on the drawing boards are not transmitting into reality. There is a visible gap between visualisation and realisation of urban development. The Census of India classifies Indian cities in four categories: statutory town, census town, urban agglomeration and outgrowth (MoHA, 2012). All these cities and towns are attaining different levels of urbanisation and complexity, and impacting diversely on the overall economic and social development of the country. Most cities undergo varying degrees of urban planning efforts. Yet Indian cities showcase complete absence of systematic urban planning efforts. It is surprising that the cities are somehow operating day-to-day activities. It is also not much evident that citizen acknowledges the role of urban planning and enquire for the same. Citizen demands basic utilities like water, sanitation, power, transport, housing and amenities like open spaces, parks, plazas, entertainment and sports facilities; but is oblivion about the significance of urban planning to create a sustainable urban environment. Most Indian urban dwellers are not even aware of urban planning and its purpose in developing a functional and sustainable city. Here I refer functional city as the city where daily life of the
residents feel pleasant due to the tangible actions and choices adopted by the city administration. A functional city has much strength that includes easy accessibility, adequate urban infrastructure, equality and non-discrimination, strong social cohesion and open and inclusive ways of city management (City of Helsinki, 2017).

Post-independence urban development quality in India did not advance much to coalesce either with the pace of economic growth or with the global standard. Recently, some increased infrastructural initiatives can be witnessed in Indian cities. However, the outcomes of such initiatives do not yield in constructive benefits either for the city or its citizens. These approaches, which are largely spasmodic in nature fall short of creating a functional city. It raises serious concerns on the existing urban development approaches and overall vision to achieve urban sustainability. While questioning the existing practices is apparent, yet immediate breakthrough is not visible. It is not that all Indian cities are organic, the planned cities are somehow functioning in a manner that is more familiar with the chaos of unplanned cities. Limited capital and capacity constrain are primarily blamed for the poor condition of Indian cities. But rarely we investigate two aspects in details – first, the contribution of a coordinated effort to plan a city with a blend of knowledge, innovation, vision and leadership, second, the knowledge of urban development process among the contemporary planning and design organisations and the quality of technical solutions. Findings from the global cases suggest that planning knowledge and technical knowhow on urban development are important tools that can lead to a sustainable and functional urbanisation. Ahluwalia (2012) stated that Indian urban planning needs a major overhaul, which is overly top-down and controlling where it should not be, and does not provide much needed guidance, coordination and integration where it should (Ahluwalia, 2012).

One may argue that urban professionals’ lack of knowledge to derive appropriate solutions negatively influence Indian cities to achieve functionality. Although it is difficult to measure quality of urban development or functionality, it is convenient to compare cities and argue about these attributes. The attributes are not necessarily confined within the outcome of a functional city but also with the process of its development. Process of city development mostly involved with the knowledge and resource personnel involved in it. I am putting forward Chandigarh as an example of a functional and orderly city. The idea of Chandigarh continues to be a subject of discussion among scholars as a commonly evoked symbol of a modern India in a globalising world (Nilsson, 1978; Gopal, 1984; Nangia, 2004; Perera, 2004; Kalia, 2006; Banerjee, 2009; Shaw, 2009; Bharne, 2011; Chalana and Sprague, 2013). It not only provided a benchmark for Indian cities for many years but also created an ideology – an expression of India’s modern urban development. The paper contributes in two ways; first, it discusses about the city development processes of Chandigarh with its visible outcomes and second, it evaluates India’s urban development approaches which includes the knowledge resources, personnel and pattern of urban development.

I am aware of the probable intellectual intricacy to consider Chandigarh as a functional city or an ideal solution for India’s messy urbanisation. I am also not claiming that Chandigarh can respond to all the woes of Indian cities. However, I may safely portray Chandigarh as the sole relevant Indian example of contemporary urban development that created a city that performs relatively well when compared with other Indian cities. With the advent of technology and growth, Chandigarh may be failing to offer an ideal infrastructural support to its occupants. Still, it offers a decent quality of living to its residents. It is possible due to the knowledge input, leadership and resource personnel involved in visualisation of the city. It is challenging but worthy to investigate the contribution of knowledge in urban planning and how knowledge limitation affects urban development. The questions underpinning this paper are:

RQ1. How urban development process occurred in India?
The research questions and goal of this paper will be responded by adhering to the following objectives:

1. to comprehend the existing urban development process in India and key learnings from it;
2. to investigate a chosen functional city and its underlined reasons for such achievements; and
3. to establish the learnings from Chandigarh and identify the gaps in comprehending its attributes in recent applications.

2. Background and methodology

Two research methodologies, namely “case study” and “analytical narrative” seem relevant to response to the aim and objectives of this paper. A case study method is usually focused on certain urban systems with a view to explain why those systems are a success and why some ended up being a failure. It mostly concentrates on the questions of efficiency. A narrative analysis seeks to understand urban development process and change (Dhingra, 2012). It appeared in disciplines such as policy analysis, urban history, social science, political science and economics. Analytical narrative evaluates the explanatory performance of new genre, using some philosophy of historical explanation, and then checks its discursive consistency, using narration (Mongin, 2016). Analytic in this approach, refers to creating a narration taken from rational arguments, particularly from the discussions of contextual understanding and derived inferences. Levi and Weingast (2016) identifies the steps toward building these inferences that include the following:

1. extracting the key actors, their goals, the sequence of options available to an actor at a given moment, and the effective rules that influence actors’ choices;
2. elaborating the strategic interactions and learnings that produce some actions and facilitates others; and
3. leading to a comparative understanding that produce testable implications even if they’re not the main assertion of the case.

This study is motivated by the desire to improve a technique, and work to untangle a theoretical or empirical outcomes. It also identifies causal inferences that are generalised from or generalisable to other cases (Levi, 2003). The paper uses secondary data such as published books, journal articles, web reports and documents to learn from the past and invoke a structured discussion. The paper utilises historical evidence, and incidents from data sources as important evidence. In a limited data environment, a detailed description and chronologically structured evidence of the facts are the appropriate approach to present the paper’s central arguments. The paper contributes in discussing the chaotic nature of Indian cities and its relation with the overall planning approaches and things that are forgotten from the great examples of the past.

The following section presents the contemporary urban development process in India. The section comprehends the existing urban development process in India and records key learnings from it.
3. Colonial and post-independence urbanisation – as it happened in India

The relevant history of modern Indian urban development has three distinct phases – the colonial legacy or mostly the British town planning tradition; the post-colonial Ford foundation paradigm; and the current era of economic liberalisation and globalisation (Banerjee, 2005). Globally urbanisation has changed tremendously during and after the industrial revolution. Many recent urban planning experiences and planning movements in the west are direct consequences of industrial revolution. With the exception of the erstwhile Union of Soviet Socialist Republics and Japan, the present urban system of the industrialised economies was almost in place before the World War I (Bairoch and Goertz, 1986). Industrialisation in the west experienced much of technological revolution that prompted big changes in city form and density. Rapid changes due to industrialisation were new and never anticipated. The consequences of industrialisation were extreme – polluted wells from sewage, improper waste disposal, high population densities, poor personal hygiene, lack of public health system, 12–16 h work days, child labour, torture, dangerous conditions, measly pay and cholera epidemics in Britain (1832, 1848 and 1866). As an immediate response, city planning emerged with legislative initiatives like sanitary reform and public health act, and spatial interventions like park movement, city beautiful movement and garden city to improve the meagre urban situation and poor living standards of people (Elliott, 2014). In the nineteenth century and most part of the twentieth century, industrialisation was not much prevalent in India. Even in the twenty-first century, industrialisation in India is less dominant than in the west or the other emerging economies like China. And yet Indian cities show the exact same symptoms like the industrialised cities during their initial phase of industrialisation. During the early industrialisation period, England lacked sufficient capital, knowledge and personnel to plan cities effectively. However, in India, these limitations are more severe (Spodek, 2013). It is yet to be seen whether India can employ the similar strategies like the industrialised west and escape from the unsustainable urban situations and achieve a sustainable urbanism. A glance on India’s approaches towards urbanisation so far may decipher its strategies to achieve a sustainable urban future.

An institutional approach towards urbanisation started during the colonial period. The British introduced urban institutions and legislative structure for urban development. The British planning systems also influenced the administrative jurisdiction, physical planning and urban architecture (Spodek, 2013). They made isolated attempts to plan and develop major cities based on regional economic productivity and export potentiality. Most of these planning efforts lead either by western architects or planners of notable fame and reputation. British architects, Sir Edwin Lutyens and Sir Herbert Baker planned New Delhi in 1911. Scottish biologist Patrick Geddes travelled in India between 1915 and 1919 and wrote a series of “exhaustive town planning reports” on 18 Indian cities. Geddes was hoping to create a “working system in India”, which could achieve an urban fabric that is both considerate of the local context and tradition, and need of the development. In 1946, German architect Otto Königsberger planned the modern city of Bhubaneswar and Jamshedpur. American architects Joseph Allen Stein and Benjamin Polk planned Durgapur Industrial Township in West Bengal.

Even after the independence the tradition of involving foreign experts for urban development continued. While looking for town planners to plan Indian cities, the first Prime Minister of India, Pt Jawaharlal Nehru observed limitation of planning knowledge among Indians. He also recognised the specialised need of town planning profession (Gopal, 1984). During the search for a town planner, Nehru was very impressed by American architect and planner Albert Mayer and his idea of urban development extended from Indian rural settings. Nehru appointed him for many planning and development works. He also contributed on the initial plan for Chandigarh (1949–1954), planning of ninth Delhi (as the capital of the new Republic of India was called) (1957–1962), and the basic development plan for the Calcutta (now Kolkata) metropolitan region (Banerjee, 2009). One may argue that the most prominent

Why Indian cities are so chaotic?
example of India’s post-independence city planning attempt is Chandigarh. It was necessary
for the State of Punjab to establish a new capital after the partition of India and Pakistan.
Thus Chandigarh, India’s most prosperous and greenest city born of dreams at the time of
the country’s worst nightmares of partition (Glancey, 2015). The planning initiatives for
Chandigarh were a landmark for India’s urban planning history. In addition of being the State
capital, planning of Chandigarh was visualised to be an example for other emerging cities.
Figure 1 narrates a brief understanding and derived inferences from the existing discussions
and literature on urban development process as it occurred in India.

Traditionally, urbanisation in India was sporadic and patchy. The colonial influences
during the industrialisation started the process of urbanisation and streamlined urban
institutions. Many notable experts on urban development visited India during this period.
After independence, the urban situation worsened. Knowledge limitation continued to be a
hindrance for urban development in India. As a result, foreign experts and expertise continue
to play a crucial role in Indian urban development process that includes Chandigarh.

4. Development of Chandigarh – a case of post-independence urbanisation
that worked for the city

During the recruitment of a western planner to build Chandigarh, Nehru favoured Mayer
who was earlier appointed as planning advisor to the Uttar Pradesh Government in 1947
(Banerjee, 2009). Nehru was personally involved in initiating the planning for Chandigarh.
For Nehru, Chandigarh was an opportunity to establish an urban expression that is more
Indian than westernised:

Nehru was searching for an “Indian modernity” in cities, a global and post-colonial reality rooted
with the homeland. The national aspirations for the new city represented in Nehru’s idea of India
and the notions of modernity. Nehru’s idea of modernity was constructed within a continuity and

![Figure 1. Contemporary urban development in India and its contexts during colonial and post-independence](image-url)
change of tradition. He wanted to build community life on a “higher” scale without breaking the traditional foundations of India, its pastoral connectivity and socio-cultural mix. His vision of “new” India presented the possibility of combining its spiritual heritage and “scientific temper” of the Western societies. (Perera, 2004)

Chandigarh was considered as a very important era in Indian urbanisation. Its visionaries believed that the success of this city in establishing an Indianite urban life could make a huge difference in its aftermath. It was an opportunity to establish city based on pastoral culture, social value, incrementality with an interconnected spatial system. Mayer probably understood the context and abled to transform it, but he did not repeat village life entirely. He comprehended functioning of an Indian city and developed a workable image. As Lynch (1960) said, the city representing an image requires identification of an object yet its distinction from others to recognise as a separable entity. Hellier (1989) argued that Mayer’s primary concern was to develop a neighbourhood unit modelled on the romanticised Indian village. While Nehru searched for “Indian modernity”, Mayer and Nowicki developed “Indianite modern” response to city planning (Hellier, 1989):

The organising principle of Mayer’s plan was the superblock, a variant of the neighbourhood unit concept with sufficient variety in housing form and density to accommodate the socio-economic diversity of an Indian city. A superblock encompasses the area within one-half mile (walking distance) of a grade school at its centre. Superblock was initially proposed by Clarence Perry for the New York regional plan, and used by Clarence Stein in the Radburn plan. He also used the site characteristics (gently sloping topography, streams, and valleys) to determine the city’s circulation and open space systems and to locate the functional foci of neighbourhood units, and accommodated bicycle traffic, schools, and business districts. Conscious of the vehicular traffic problems of US cities and the pedestrian culture of traditional Indian cities, Mayer’s plan attempted to isolate high speed vehicles from the slow moving ones, and to contain the quotidian life of the pedestrian culture largely within the defined neighbourhoods, thus minimising conflict with vehicular traffic. (Banerjee, 2009)

In Mayer’s plan of Chandigarh, the traditional approach of city growth encircling power centres like religious authority, imperial palace or parliament house gave away to common citizens with activities like commercial complexes, civic centre and green plaza at the heart of the city. Mayer proposed the Capitol Complex at the North relatively away from the city centre. Worried about the US transit system, Mayer put specific attention towards segregating vehicular traffic with non-motorised traffic. Mayer and Nowicki had some understanding of the ubiquitous informal economy in traditional Indian cities that always mixed with social classes, as serving classes needed to live near the recipient classes. The architectural expressions including housing solutions considered the close proximity between serving and recipient with a mix of different socio-economic category.

Incidentally, Mayer discontinued his work on Chandigarh after the death of Nowicki in a plane crash. Husband–wife team of English architects – Edwin Maxwell Fry and Jane Drew who were pre-occupied with ongoing work suggested Le Corbusier as a possible lead. Corbusier arrived in India in 1951, and within six weeks he “rationalised” the curved streets of Mayer’s scheme into an orthogonal grid, re-apportioned its proposed “Villages” into “Sectors” thrice as large, reduced the quantity of roads, and increased the overall density (Bharne, 2011):

Pierre Jeanneret, Maxwell Fry and Jane Drew supported Corbusier’s subsequent plan. Corbusier significantly changed Mayer’s idea but was immensely benefitted from his work because he did not have to start the work from beginning. For Corbusier, the city was not a place where inhabitants determined its role in their daily lives; rather, the city determined the roles of its inhabitants. The principal spatial focus of each team was also contrasting. While Corbusier viewed the city from the capitol complex, the Mayer–Nowicki team approached it from the neighbourhood. The neighbourhood was the basic generative unit, with the design team concerned to promote its strength, unity and identity and beginning the planning process from this point. In Mayer’s words, “we did not plan down to (the neighbourhoods) but up from them”. (Perera, 2004)
He has intellectual difference with Mayer’s planning but adapted Mayer’s scheme in principal. Corbusier’s adaptation of Mayer’s original scheme was highly segregated by rank, income and social class, reflecting long Indian tradition of social segregation system (Dumont, 1970). Many argue that understanding of Indian living pattern with spatial proximity between castes for urban services was reflected in Mayer’s plan. Corbusier’s may have overlooked this crucial aspect due to his less exposure in India. Today Mayer’s contribution in Chandigarh is not discussed much like Corbusier. Arguably the tradition of city functional is reflected through Mayer’s work, especially in the way he visualised the neighbourhoods, housing districts, segregated major functional districts and a hierarchical circulation system (Perera, 2004; Banerjee, 2009). Rhetorical vision of inspiration and celebration of culture through city planning may have been lost after Mayer’s departure. The idea of planning Chandigarh with pastoral Indian ideology to reminiscence cities with bucolic values got misplaced in Corbusier’s planning. However, there are evidence, which suggest Nehru’s vision has merits in its own place. The idea to build the city (of Chandigarh) incrementally (as living organism) with an interconnected system is realised elsewhere in the world. Tokyo is one such example, which is built incrementally – step by step (Echanove and Srivastava, 2013).

Corbusier inscribed two sectors (Sectors 8 and 21) of Mayer’s original plan with rectangular grids, and enlarged the sectors to roughly 4,000 by 2,600 feet. He planned Chandigarh under the patronage of Nehru and yet enjoyed relative freedom from the State authority (Scott, 1998). He worked with the principle of the “Sectors” and the “V7 rules”, and designed four buildings of the Capital Complex – the High Court, Secretariat, Assembly and Museum of Knowledge including the surrounding park. The rest of the design and implementation, involving all the housing and services, were implemented by Maxwell Fry, Jane Drew, his cousin Pierre Jeanneret and eight Indian architects. Although Corbusier favoured modernist high-rise high-density integrated residential unit, but later settled with low-density horizontal city, retaining some of its Garden City character. He was reclusive about the design of residential units and its overall social composition (Shaw, 2009).

Although the monuments created by Le Corbusier brought worldwide attention to Chandigarh, the lesser-known housing structures with an average height of two and half stories played an important role in the decolonisation process. They were a part of the social agenda and rebuilding of a new India following an egalitarian principles and providing a better quality of life to all its citizens (Nangia, 2004; Shaw, 2009).

Chandigarh did not fully emerge as per Nehru’s vision and the underlying philosophy of establishing an Indian pastoral urban precinct. Yet Nehru praised the city after its completion and today the city represents the most prosperous and functional Indian city. Legislative support including the local building byelaws helped the city to channelise growth and restrict haphazard development. The following table extracts key actors, their goals and effective consequences that collectively contributed in Chandigarh’s success to become a “functional city” (Table I).

Chandigarh developed as a low-density horizontal city, perhaps created India’s best example of city development. It was achieved due to multiple inputs, discussions, debate and certain compromise from all the actors. It would be interesting to explore the urbanisation pattern in remaining Indian cities, as Chandigarh was developing steadily.

5. Post-independence urbanisation in Indian cities – exploring contrasting trend and its impact today

After the independence, Indian cities inherited critical urban situations that degenerated by massive flow of refugees and rural–urban migration. Between 1941 and 1951, the population of Indian cities grew by 41 per cent and the war together with the famine of 1942 hastened the rural migration to cities. Between 1951 and 1961, an increment of 26 per cent urban population is recorded. Approximately, 18 per cent of India’s total population was put into cities by the
end of the decade (Brush, 1962). As Chandigarh was gradually taking shape from scratch, already built Indian cities are reeling under pressure from population expansion, inadequate infrastructure, random service delivery and poor hygienic condition. Refugee rehabilitation was critical in the post-partition years (Shaw, 2009). The situation was extremely serious for a newly independent country, which did not have much experiences in urban development and city management. For long, India had been an agrarian economy. Even during the freedom movement, rural regime was an ideological preference for Indians than urban living. Mahatma Gandhi’s idea of village life was to revive the traditional Indian legacy of a functional autonomous village republic (Gnaneshwar, 1995; Biswas et al., 2012).

Acquiring knowledge for urban development and city management are never easy. The situation became much demanding with the limited availability of knowledgeable professionals and institutional arrangements. Knowledge on engineering and architecture was relatively new in India. First all-India professional organisation for indigenous architects was formed in 1930, and it was not until the 1960s that a generation of Indian-trained architects began to emerge. The Institute of Town Planners India (ITPI) established in 1951. ITPI is a professional town planning organisation on the lines of the Royal Town Planning Institute, London. In the late 1950s, academic institutions started to teach town planning alongside architecture (Shaw, 2009). In 1955, IIT Kharagpur introduced urban

<table>
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<tr>
<th>Actors</th>
<th>Goals</th>
<th>Effective consequences</th>
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<tr>
<td>Pt Jawaharlal Nehru</td>
<td>To establish Indian modernity in cities – showcase through the development of Chandigarh. To build community life without breaking the traditional foundations of India, its pastoral connectivity and socio-cultural mix.</td>
<td>Appointed Albert Mayer to plan for Chandigarh. Leadership, guidance and continuous engagement with the chief planner and his team to derive the right balance between spiritual Indian heritage – pastoral quality with modern urban living with socio-cultural mix.</td>
</tr>
<tr>
<td>Albert Mayer</td>
<td>To combine India’s spiritual heritage and ‘scientific temper’ of the Western societies. To develop functioning of an Indian city as a village and developed a workable image.</td>
<td>Developed a neighbourhood unit modelled on the romanticised Indian village. Adopted fan shaped city form with superblocks - a variant of the neighbourhood unit concept, curved streets, with sufficient variety in housing form and density to accommodate the socio-economic diversity of an Indian city. Established neighbourhood as the basic generative unit, to promote its strength, unity and identity. Planned up from the neighbourhoods to the city. Isolated high speed vehicles from the slow moving ones, and to contain the pedestrian India culture largely within the defined neighbourhoods, thus minimising conflict with vehicular traffic.</td>
</tr>
<tr>
<td>Le Corbusier</td>
<td>To develop a city that determine the roles of its inhabitants and thus develop a new urban culture.</td>
<td>Created principal spatial focus as the capital complex as the identity of the city. Rationalised curved streets into an orthogonal grid, revised villages’ into sectors. Reduced quantity of roads, and increased the overall density, and worked with the principle of V7 rules. Established low-density horizontal city, retaining some of its garden city character.</td>
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**Table I.** Key actors, their goals, and the consequences affected due to the actors’ choices.

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planning as a regular academic programme. Presently, approximately 23 academic institutions recognised by ITPI, are offering planning as a regular programme.

Inherited with the lingering urban conundrum, India’s approach to urban development in already built Indian cities was starkly different from that of Chandigarh. Primary objectives were to restrict haphazard growth and restore some kind of order in urbanisation. After independence, the establishment of institutional authorities to manage urban development was given the top priority. It follows the British system namely “disciplinary approach” consisting of the creation of urban institutions and legislative framework in cities (Elliott, 2014). Among the most significant institutions established by the British, the “Bombay improvement trust” and the “Calcutta (Kolkata) improvement trust” were of the paramount importance. These institutions were created through an act of the Parliament (Biswas et al., 2013). Development authorities were established across many cities under the corresponding State legislation. These authorities function as a parastatal organisation and plan for urban and metropolitan development. These authorities are unlike municipal corporations and usually oversee the entire city or metropolitan area consisting of multiple city administrations (Biswas and Kidokoro, 2011).

Individual authorship for planning in Chandigarh was completely different from this institutional authorship of planning of already built Indian cities. Delhi Development Authority, established in 1957 by an act of the Parliament, drafted Delhi Master Plan 1962 with the support from Ford Foundation. However, it was not possible to visualise development strategies for all cities and channelise its growth direction. The institutional setup for cities considered to perform these responsibilities. However, Nehru continued his attention in developing a meaningful urban expression in Indian cities. Inviting planners from the USA to assist planning for the new capital was a significant indication of his keen interest (Breese, 1974). Nehru’s insistence on bringing back Mayer to plan New Delhi suggests his trust in Mayer and contrition on their inability as a team to conclude the vision in Chandigarh. However, Ford Foundation was an important actor during the planning of New Delhi. Goodfriend in Banerjee (2009) mentioned that Mayer suggested inviting public participation in the preparation of the master plan. But many of Mayer’s initiative including the necessity of a public participation consultant fetch no response from Ford Foundation (Banerjee, 2009). Eventually, Delhi Master Plan 1962 was accepted and enacted for implementation. However, a later review of the master plan revealed that the crucial strategic interventions suggested in the master plan were never implemented. Planners working for Ford Foundation believed that implementation is the most persisting Indian problem in city development due to the overlap of different governance jurisdictions (Biswas and Maurya, 2018). Till date, not many Indian cities experienced a comprehensive physical planning effort. In the absence of physical planning, urban development augmented through urban policy and overall sectorial funding to urban infrastructure. At a later stage, funds were put forward to prepare master plans by the institutional and collective authorship of the development authorities. Yet many cities did not prepare master plan either due to knowledge limitation or negligence about the very idea of planning. Reluctance in India’s city planning may be attributed to the political economy of post-colonial India. Historically, cities occupy an ambivalent place in Indian imagination, despite most of its leaders are from cities and towns (Prakash, 2013; Nair et al., 2016). In addition to this reluctance, four other major limitations may have dented the efforts of orderly urbanisation in India. These are:

1. limited intellectual and technical standard of master plan;
2. absence of roadmaps to transmitting master plan’s recommendation in reality;
3. (unlike Chandigarh) Dearth of strategies to visualise built form and its socio-economic and cultural correlation with the city; and
limited understanding of the relationship between the physical, social, and functional planning with the overall economic planning.

This top–down approach of city development through national policy and associated funding came along with the national planning process through the Planning Commission and the Five Year Plan(s). The Government established the “Planning Commission” to promote a rapid rise of people’s standard of living through the efficient use of the country’s resources, increase production, and offer employment opportunities to all. Initial years of governance experience revealed the need for comprehensive planning based on a careful appraisal of resources and an objective analysis of all the relevant economic factors (Government of India, 1950). The Planning Commission was authorised to make an assessment of the country’s resources, augment deficient resources, and formulate plans for an effective and balanced utilisation of these resources. It was felt that the diversity between the States need some direction towards envisioning equal standard of living across the country. A central institution with the capacity to analyse, comprehend and formulate development perspective would be more effective for this task. Thus planning in post-colonial India associated with this national level planning through Five Year Plan(s) (Banerjee, 2005). But achieving an orderly urbanisation from the chaotic Indian cities through Five Year Plans turned out to be a distant achievement.

Rondinelli (1991) described Indian urbanisation as a stepchild to national economic policies, which received attention only when critical urban problems caused serious difficulties (Rondinelli, 1991). The initial three Five Year Plans (1951–1966) focused on increasing food production, developing heavy and basic industries and repairing the damage of partition rather urbanisation (Shaw, 1996; Nair et al., 2016). Planning at central Government was sectorial, which put very little attentions to spatial aspects (Shaw, 2004). By the end of 1970s, Indian cities were struggling with all possible symptoms of a city with fragmented infrastructure, haphazard growth, poverty and inequality, slum and informal settlement, congestion and pollution. Much needed effort in urban development came in the 1980s. Remarkably, the Planning Commission acknowledged the correlation between urbanisation and economic growth only in the eighth Five Year Plan (1992–1997). The first ever “National Commission on Urbanisation” constituted in the eighties, which submitted its report in 1988. It followed by the 74th Constitutional Amendment Act 1992 (74th CAA 1992), which decentralised administrative structure in three tiers and established Urban Local Body as a statutory administrative organisation. Today, Indian cities represent an unimaginable disorganised urban expression. There are some successes but India yet to achieve comprehensive and integrated expressions of urban development.

Strategic interactions from the Government to mitigate the emerging urban crisis in India leads to the following comparative understanding with prolonged implications that is relevant even today (Figure 2).

Immediately after the independence, the influx of refugees (in urban centres) due to the partition and rural–urban migration created severe problems. In the absence of domestic and international experts, the Government tried to control the urban chaos trough centralised policy directives, legislative measures and institutional arrangement. However, the consequences of these strategies yielded more concerns than solutions. Among the concerns, implementation of the master plan, the decline of knowledge and capacity among civic authorities and lacunas of an Indianite urban expression are particularly worrisome. In 1991, the economic liberalisation opened up the Indian economy and connected it with the globalised world. The era of liberalisation and decentralised institutions brought more opportunities for the Indian economy and a fresh set of challenges for Indian cities, which were never prepared for such a dynamic transformation.
6. Urbanisation in post-liberalised India – contemporary urban development

By the early 1900s both Great Britain and the USA had become predominantly urbanised nations. Since then, urbanisation has been occurring around the globe at a rapid rate (Houghton Mifflin Harcourt, 2016). In 1991, the percentage of urban population in India was 25.7 per cent, which increased to almost 32 per cent in 2011 (Government of India, 2012). Economic liberalisation put India’s growth towards a higher trajectory and altered its composition totally. Service sector performed significantly higher followed by the industrial sector. As a result, wealth began to concentrate in the service sector which was further facilitated by information technology, banking and telecom sector’s reform. All these development culminated into ample job opportunities in cities (Insights on India, 2014).

After the liberalisation, "metropolitanisation" became a de facto for Indian cities. In addition, it became more significant with the creation of a robust middle class and a shift of income distribution in cities. The shift gave rise to more non-food consumption and demand for specific typology of housing and real estate. KPMG (2014) predicted that the total investment in real-estate sector in India would reach to US$ 853bn by 2028 (KPMG, 2014).

The Government adopted two pronged strategies – creation of new towns, and densification and regeneration of the existing cities with infrastructural augmentation. Noida, Gurgaon, New town Rajarhat, Navi Mumbai, Naya Raipur and Amaravati are some of the prominent new towns of recent times.

Involvement of experts from the west is not so frequent in contemporary city development. Envisaging urbanisation through master plan has become the new normal for Indian city planning approach. The gridiron pattern and the “principles of sectors” introduced by Corbusier deeply inscribed into the city planning expression of Indian new towns. Banerjee (2009) affirmed that the sector idea became the template of new town development throughout India. It is more prevalent in cities planned by public organisations like development authorities (Banerjee, 2009). Prior to Chandigarh, there is not much evidence of sector-based planning in earlier Indian cities. The figure below presents few sectors-based city planning examples from post-colonial and post-liberalisation period (i.e. Salt Lake City, Noida, Gurgaon, Navi Mumbai, Naya Raipur and Amaravati) (Figure 3).

With this new sector-based planning, Nehru’s idea of achieving Indian modernity by establishing rural tranquillity in an urban precinct elapsed away. Now, the sectors are leased among real estate, housing finance, and development authorities for investment in housing, commercial complexes, and other amenities. The privatisation of cities became the
new trend in the post-liberalised Indian cities. The development authorities confine its role
as planning institution only in preparing a master plan based on sectorial ideas and creating
networking through transport corridors. These sectors are so big that only way to travel
even to neighbouring sectors is by motorised vehicles. Land parcels in sectors are leased out
to private investors who look to maximise return on investment through rampant real-estate
development. Each land parcels are cordoned off with high walls with a restricted public
movement that follows the modernist approach of high-rise towers with inner open spaces
and amenities exclusively for its own residents (Plate 1).

Density of these gated complexes varies between 1,000 and 1,200 persons per hectare,
which is significantly higher than Chandigarh or any metropolitan cities in India. Privatisation
in cities have created such a scenario of splintered urbanism where private
means emerged as the solutions to the paucity of integrated public infrastructure (Roy,
2009). Noida, Greater Noida and Gurgaon in National Capital Region of Delhi, Rajarhat
Kolkata are prominent examples of such modernist city in India. The modernist approach
has diminished the identity of Indian cities and attracted a huge population influx in
informal sectors leading to further chaos in cities. In 1991, Gurgaon district had an urban
population of 121,000. By 2001, it had expanded to 870,000 and by 2011 to 1.5m. As of 2013,
nearly half of the Fortune 500 Companies have operations in Gurgaon. As a result, Gurgaon
has become a leading destination for India’s young middle-class workers in the tech
industry (Rajagopalan and Tabarrok, 2014).

Surprisingly all the new towns including Gurgaon, are struggling with infrastructure
decay, slum breeding, pollution, congestion, insecurity and low quality of life. There is no
single answer to these problems, which is so complex and persisting. It is also puzzling to
know that some 2,000 Indian cities now have master plans, and yet all displaying the
problems of haphazard unsustainable growth (UN-Habitat, 2010). For many years, arguments
for India’s dismal cities surrounded over the absence of master plans but it seems that the existence of master plans are not good enough to alter this grim situation. Planning in India has remained technocratic with land use, physical planning and infrastructure being the central concern, with little attention to integration between spatial and environmental, economic and social dimensions that shape cities and drive changes (Todes et al., 2010). Institutional authorship of city planning through "development authorities" are also not yielding the desirable results in Indian cities. Somehow the process of urbanisation has not blended in India and the product is not inspiring enough (Reddy, 2014). This persistent failure of planning or the splintering of cities through privatisation of planning seems to be the convincing and adequate explanations for the crisis of Indian cities (Roy, 2009).

From 2005 onwards, existing cities funded for the regeneration of city infrastructure that may support the increasing population pressure. Urban renewal programmes such as Jawaharlal Nehru National Urban Renewal Mission, Atal Mission for Rejuvenation and Urban Transformation and smart city mission focus on city cores to upgrade infrastructure, e-governance and urban amenities. These missions are a top-down approach, driven by the Union Government and broken down into projects, and its implementation within a stipulated time. These missions are not meant to achieving long-term goals, regenerating cities, establishing visions and identities. The cities required to prepare proposals or infrastructure plan and list down the projects for funding. Such mission-based programmes are extremely volatile that alter with the change of Governments. These programmes aim for immediate achievements, and at best can be seen as an emergent effort to somehow heal the city’s broken infrastructure. But these efforts are unlikely to salvage the cities’ downturn and establish a decent quality of life in Indian cities. There are many reasons for these programmes’ ill fate but the main reason is that the majority of these gargantuan schemes require a political resolve and financial wherewithal that few authorities could muster (Scott, 1998). Authors also argue that after the economic reform, the Government perceives urban development as a business opportunity and a tool to create jobs, rather than to create a sustainable urban environment. With the looming uncertainty of capital investment and maintaining the same during its services life, Indian policymakers missed the basic connotations with these large...
technological systems and social networks. These networks are closely bound up within wider sociotechnical, political and cultural complexes which have contingent effects in different places and different times (Tarr and Dupuy, 1998; Joerges, 1999).

The gradual evolution of urban planning severely affected by the introduction of economic liberalisation. There was no visionary direction to exploit the potential of liberalisation and lead urban development to support both economic development and nurturing quality of urban life. In the end, India chose the convenient option to cruise along this path of city development. The existing indications are not very promising. The future of such development and its implications in a society or a country as a whole remained to be seen.

The paper presents elaborated discussions to highlight the significant difference in city planning approaches to Chandigarh and post-liberalised city development process. The differences are presented in the following table (Table II).

7. Discussions and conclusion

The study sets out to discuss the city development processes of Chandigarh as the benchmark to evaluate India’s urban development approaches, which include the knowledge resources, personnel and pattern of urban development. The paper argues that the lack of planning knowledge and application has severely impacted the outcome of existing Indian cities. The paper contributes to developing a structured argument that interconnects chaos in Indian urban development with planning knowledge and application. The narratives are presented by elaborating strategic learning from the city development process that leads to a comprehensive understanding of the facts, and by extracting key actors, their contributions and influences of choices in the urban development process.

History of contemporary Indian urbanisation is not more than 200 years. Of which, the past 70 years are more critical because of its speed and emerging complexity. India approached urban development through green field project and rejuvenation of existing cities as brownfield development. However, one may argue that Chandigarh remained the only city that showcased some traits of a functional city. Chandigarh patronised by Pt Jawaharlal Nehru and the State Government of Punjab and planned by group of individuals. It has a focused vision, development philosophy and a clear political leadership. It helps to ascertain appropriate foreign experts with technical knowledge and Indian fervour at the helm. Although Mayer’s departure may have altered Chandigarh’s outcome from its initial philosophies, yet the city able to attain a distinction of a functional city. The project created much enthusiasm among the Local Government, who was extremely supportive in laying out a legislative structure and creating an institutional framework and capacity building. As a result, the city developed slowly yet firmly in spite of financial limitation. Today the citizen of Chandigarh takes immense pride of their city. Chandigarh’s orthogonal grid and sector-based planning became the main expression of contemporary Indian urban planning. Unlike sector-based planning, the integrated planning approach of Chandigarh has not find its scope in contemporary urban planning.

The paper argues that the post-liberalised urban development is visualised more as a business opportunity and job creation rather than to improve the quality of urban living. The static master plan approach and sale of land to private developers suggest the Government’s aim of immediate return through real-estate development rather creating a sustainable urban future. The static nature of master plans requires a long time for preparation and poses extreme difficulty in updating. It neither provides any guidelines for implementation nor evaluates the costs of development or the methods of financing them. Master plans are often based on an unrealistic appraisal of the economic potential of the
planning areas and, in some cases, on the needs. It seldom provides a compelling ratio of detailed land use and elaborate land use regulation or control (United Nations, 1985). The aim of cities and municipal planning departments in India remains to produce more such plans (UN-Habitat, 2010). Countries such as the UK have already shifted away from master plan. Njoh (2008) that master plan centred on the production of plans on paper, with little attention to implementation, needed a much closer inspection as the primary tool of city development in India (Njoh, 2008). Ideally, the purpose of a master plan is to create a city vision that is supported by a detailed spatial planning strategy to attain its' visions. In India, the master plan became the only tool of a city planning exercise, whereas it should have

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Chandigarh</th>
<th>Post-liberalisation city development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning authorship</td>
<td>A group of individuals lead by an architect-planner</td>
<td>Public development authority</td>
</tr>
<tr>
<td>Investment</td>
<td>Mostly public investment</td>
<td>Combination of public and private, where trunk infrastructure is created by the Government and development like housing, commercial complexes are done by the private enterprises</td>
</tr>
<tr>
<td>City's economic structure</td>
<td>Indigenous people mostly involved in public sector service, commercial and institutional activities;</td>
<td>Cosmopolitan character with service sector dominated individuals</td>
</tr>
<tr>
<td>City form</td>
<td>Mayer established superblock – a variant of the neighbourhood – Indian village unit as the organising principle with sufficient variety in housing form and density to accommodate the socio-economic diversity of an Indian city. A superblock encompasses with curvilinear roads, segregating vehicular and pedestrian traffic within one-half mile (walking distance) of a grade school at its centre. Later Corbusier changed the neighbourhood - Indian village unit into an orthogonal grids of sectors, which is three times bigger in area and density.</td>
<td>Mostly orthogonal grids with segregated land use that distribute city into sectors such as residential, commercial, institutional, recreational etc</td>
</tr>
<tr>
<td>Mobility</td>
<td>Mixed land use to discourage automobile dependence</td>
<td>Segregated land use promote automobile use and unsafe roads</td>
</tr>
<tr>
<td>Housing</td>
<td>Different housing typologies within a neighbourhood to consider close proximity between serving and recipient classes with a mix of different socio-economic category. Less propensity of development of informal settlements or slum.</td>
<td>No control on housing typologies or socio-economic mix. The proximity between serving and recipient classes are lost. Development of gated communities and breeding of slums and informal settlements</td>
</tr>
<tr>
<td>Development control</td>
<td>An appropriate development control regulations that includes urban design guidelines, sight line, density and height control, architectural design and material control, etc.</td>
<td>Lands are sold to private developers who develop the land as per the land use and sell in the market. No urban design guidelines, architectural or material control.</td>
</tr>
<tr>
<td>Planning approach</td>
<td>The whole city planned as one unit with patches of eco-park and green spaces that penetrates within the neighbourhood. Basic plan or master plan supported by building regulations, design of housing typologies and its distribution among the concerned class of people, construction of public buildings, landscape zone, streets, community parks, etc.</td>
<td>The city has a master plan where the end product is a land use map. Master plans are not supplemented by perceptual form of the city to guide the physical development.</td>
</tr>
</tbody>
</table>

Table II. Gaps between planning approaches in Chandigarh and post-liberalised new towns
been the beginning of the entire urban development exercise. It correlates with my argument that city development has become a top-down approach rather than a bottom-up approach from a neighbourhood – as showcased by Mayer and Nowicki. The widespread penetration of India’s informal economy and social hierarchy of serving and recipient class have no influence in the present method of city development.

Institutional leadership of city development through public development authorities are not working in India. In comparison to the planners of Chandigarh, there is significant lacuna in the depth of knowledge and skills among the officials of public development authorities. The academic and professional institutions are not delivering enough professionals with world class and pragmatic knowledge, who may comprehend the urban situation properly and think of creative solutions. Public participation in city development is another weak area. During Delhi Master Plan 1962, Mayer tried to inculcate the concept of physical infrastructure with public participation and relating the same with social and functional planning of the city. However, the post-liberalised modernist city development approaches tend to fulfil the immediate demand and showcase engineering features. It is true that infrastructure unevenly binds spaces across cities and regions but it is important to recognise the configurations of infrastructure networks imbued with social, economic, ecological and political power to benefit from the material and social dynamics, and divisions, within and between urban spaces (Graham and Marvin, 2001). A social-constructivist image of technological development is not only in building up technology in cities but to offer possibilities and changes in choosing such technology that may prosper a closely related “socio-technical processes” (Bijker, 1993). Today, public participation and inclusiveness has become a punchline that exists in city development report but not in real. The benefit of the common is not practiced in Indian cities, which is extremely biased towards the affluent class. It is because cities are viewed as an economic contributor rather than a place to live. Historically, social biases to common goods have always been designed into urban infrastructure systems, whether intentionally or unintentionally. In ancient Rome, for example, the city’s sophisticated water network was organised to deliver first to public fountains, then to public baths, and finally to individual dwellings, in the event of insufficient flow (Öffner, 1999).

Chandigarh showcased an ideal example of a functional city and process to supplement physical development envisioned in the overall planning. It also showcased the methods to integrate the informality and social hierarchy into space making, neighbourhood planning and housing design. Delhi Master Plan 1962 left behind valid lessons of citizen engagement and urban development for brownfield development. But the post-liberalisation modernist approach in Indian urban development is mostly ignorant about these lessons. This paper contributes to reinvigorating the aura of Chandigarh and its contribution in developing an Indian city with its own identity. It also reflects upon the series of failure among the recent city planning endeavours, and the possibilities of learning from the successful cases.

References


Further reading
Sagar, J. (1999), “Chandigarh: an overview”, A + D: Architecture + Design, p. 120.

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Assessing sustainable housing indicators: a structural equation modeling analysis

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Hossein Hataminejad
University of Tehran, Tehran, Iran

Abstract

Purpose – The purpose of this paper is to propose the sustainable housing (SH) model for the housing of Region-one of Mashhad city in Iran.

Design/methodology/approach – Building the SH particularly increases mitigation measures as well as creates healthier environments for inhabitants by decreasing harmful environmental and physical effects. This research in terms of the target is applied research that has been done with the descriptive-analytical method. The research population is residents who live in the Region-one of Mashhad, with a statistical sample of 384 people. The responses were collected from the questionnaire, and structural equation modeling (SEM) was employed to illustrate the research SH model in AMOS software.

Findings – The findings indicate that the suitability of the housing model with meeting needs together with the quality of the health situation in housing has the most influences, and in contrast, the number of residential units with building permits besides the amount of home green space has the least influences on the sustainability of housing in the region.

Research limitations/implications – The results can offer valuable insights for helping the sustainability of housing in the studied area and similar cases, which may vary in a different context.

Originality/value – The new aspect of the study is to provide the SH model by SEM, which has not been investigated in almost all previous research. This paper makes a contribution to the understanding of the physical and environmental components that affect the sustainability of housing in Region-one of Mashhad city in Iran according to respond to the needs of both lifestyles: pilgrims-tourists and residents. The results can also contribute to housing stabilizing in other developing countries, especially the pilgrimage and tourism countries.

Keywords Sustainability, Structural equation modelling, Sustainable housing, Environmental effects, Physical effects, SH model

Paper type Research paper

1. Introduction

The rapid growth of the population has caused many problems in cities, the most important of which is the issue of housing. In the meantime, the highest urban population growth has been anticipated for Asia, Africa (Li et al., 2013; Seto et al., 2012) and Latin America (García-Ayllón, 2016). The recent decades have witnessed a sharp rise in demand for housing, as a result of the combination of economic, demographic and social factors (Norris and Redmond, 2007); however, with a few exceptions, housing and its regeneration are relatively neglected topics in the sustainable development literature (Bhatti, 2001; Tosics, 2004; Hall and Purchase, 2006; Williams and Dair, 2007).

At the individual level, if one moves to a new city to take up employment or study, the first priority is normally to find a place to live (Gurran and Bramley, 2017, p. 46). Various aspects of housing construction, design, use and demolition can have significant impacts on the environment (Huby, 1998). The main aim of housing is to create an adaptable environment with human life. In other words, besides providing the personal needs of residents (e.g. sleep, food, resting, protection against climate and nature), their qualitative and social needs should also be fulfilled (Pourdelhamedi, 2012; Hosseinalipour and Shariatnia, 2010).
The city of Mashhad, which is the second largest metropolis in the country, is located in northeastern Iran. This city has some main issues such as the presence of active faults, diverse pollution, depreciation of arterial roads and poverty, and also is facing the problems of housing shortages and bad housing. Regarding the annual attraction of millions of tourists and pilgrims, the sustainability of housing in Mashhad requires some definite measures. Region-one of Mashhad Municipality has gradually transformed due to its position at the city center. Consequently, any planning for residential areas in this region, in addition to responding to the needs of downtown residents, should also strengthen the needs of tourists and pilgrims. Also, settlement conditions and living conditions in Mashhad have been inconsistent regarding urban sustainable development criteria (Ivani and Rostami, 2014). One-seventh of the inhabitants of informal settlements of 25 large cities live in Mashhad, and the rate of population of informal settlements to the whole population is higher compared to the national average (Alaedini and Naseri, 2008), which has caused much worse conditions of housing in this city and this demands a precise recognition of the issue. Moreover, in Mashhad, housing demand is rising for local residents (Khakpoor and Shakiba, 2013). On the other hand, this city is the center of immigration centers (Ebrahimi et al., 2014) and accepts millions of pilgrims and tourists annually (Esmaili and Fallah Ghalhari, 2014). There are many successful analyzing the sustainable housing (SH) studies in the literature but there are no clear research directions for Mashhad, especially Region-one of this city (Tavakoli et al., 2017; Imani et al., 2019; Brandli et al., 2007; Shayan et al., 2014; Mostaghim, 2014; Safronova et al., 2017). Therefore, the lack of any proposing of SH-related research in this city and region represents a significant issue that needs to be addressed.

Thus far, many publications have emphasized on the subject of SH indicators. These studies have proposed various indicators. Winston and Pareja Eastaway (2007) examined the key international sustainable development indicator sets to assess the extent to which they include housing indicators. They investigated whether or not these housing indicators have environmental, economic and social dimensions. Tavakoli et al. (2017) suggested that in addition to aspects of sustainability (economic, social and environmental), factors such as cultural and attention to the flexibility according to Iranian households, design SH should be considered. Yang and Yang (2014) established a hierarchical model that encompasses critical factors affecting the implementation of SH in Australia. In most cases, the emphasis is on the literature review of comprehension of criteria and indicator to analyze SH. For example, Ming Yip et al. (2017) reviewed previous studies on SH development to identify the characteristics, trends, indicators or parameters used by previous researchers in assessing the development of SH. Roshanfekr et al. (2016) developed introductory information on SH according to individual knowledge along with a literature review of evaluating and comprehension of SH criteria.

However, other studies focused on the establishment of indicator systems and rarely pays attention to propose the SH model. In this paper, the structural equation modeling (SEM) approach has been used to build a sustainability housing model.

To put it briefly, the present research, with the aim of introducing various indicators of SH and evaluating the SH model, provides a way to achieve SH in the case study and similar areas. The paper is divided into six sections. Section 2 covers and reviews the literature on SH. The population and sample selection are explained in the Section 3. Section 4 discusses an outline of the methodology, including methods used in data analysis, research components and the framework of the research. Before the final conclusions, results from descriptive statistics and the SEM analysis and discussion are presented.

2. Sustainable housing

As stated by the US Green Building Council (2014), “A home is more than just shelter; homes are the most important buildings in our lives” (Darko et al., 2018), whereas, in contrast, the bricks and the mortar we live and work in are no longer keeping us safe as houses
Residential buildings account for a substantial portion of building energy consumption in the world (Kneifel, 2010; Pacheco et al., 2012). Housing consumes a massive quantity of energy and resources, creates waste and pollution, and directly affects human social cultural life (Huong and Soebarto, 2003). Kneifel (2010) stated that the housing industry plays an important role in accelerating the spread of the energy crisis in most countries. Therefore, housing, an essential aspect of quality of life, plays a significant role, even as a core (Roshanfekr et al., 2016), in sustainable development (Winston and Pareja Eastaway, 2007). Furthermore, housing is one of the most important public policies affecting urban development and, as such, it has a significant potential to contribute to sustainability (Tosics, 2004).

Many of the major international statements on sustainable development include housing or settlement strategies (Li Yi Man, 2012). Miller and Buys (2012) believe SH as a product is strongly influenced by specific urban context that extends users’ vision of sustainability. But in general, nowadays, SH is very different from what used to exist within primitive society or in the Middle Ages. In the nineteenth century, industrial workers were unable to obtain SH standards (Maliene and Malys, 2009). So, the house-building sector has thus undergone a paradigm change, with green or SH becoming a new orthodoxy (Yau, 2012). However, housing is linked to sustainability in a number of important ways. For example, various aspects of the location, construction, design, management/maintenance and use of housing can have significant negative effects on the environment (Tosics, 2004; Winston, 2007). Furthermore, SH may result in social advantages such as better consumer confidence, increased functionality and durability, less maintenance, a better reputation and, most importantly, improved public health (Yates, 2001; Pilkington et al., 2011; Yang and Yang, 2014). For instance, high-density congested housing has a negative impact on mental health, both on account of poor physical environment (Xiao et al., 2018).

Overall, sustainability is a process; sustainable development is the product. The process must, in the field of housing, address five distinct fields:

1. the conservation of natural resources (land, energy, water);
2. the sensible re-use of man-made resources;
3. maintenance of ecosystems and their regenerative potential;
4. equity between generations, peoples and classes; and
5. provision of health, safety and security (Edwards and Turrent, 2000).

According to the definition presented above, although conventional housing projects are featured with huge environmental effects, SH projects aim to minimize their effects on the environment, enhance the health conditions of occupants and the return on investment to local community and developers, and promote lifecycle considerations during their planning and development process (Robichaud and Anantatmula, 2011). Accordingly, the focus of the present study is to analyze the impact of environmental and physical dimensions on housing sustainability.

3. Population and sample
Mashhad is the second largest metropolis in Iran and the capital of Razavi Khorasan Province. The city is located at 36° 20′ N latitude and 59° 35′ E longitude (Mirkatouli et al., 2018). It accepts 10–15m pilgrims and tourists annually in such a way that it holds the title of the second largest holy city in the Islam world and the second national metropolitan in terms of population (Mafi and Saghayi, 2008). The case study is Region-one of Mashhad municipality, the most developed region, which has a good position since it is located in the urban center. With regards to the Holy Shrine of Imam Reza (AS), which is the main tourism and pilgrim attraction of Mashhad, housing stabilizing in this region should be able to respond to the needs of both lifestyles: pilgrims-tourists and residents. According to the
4. Methodology

4.1 Procedure

In this research, the method of questionnaire survey, which is a systematic method of gathering data on the basis of a sample (Tan, 2011), has been used to collect residents’ opinions of Region-one of Mashhad Municipality. The statistical population of this study is the people who live in the Region-one of Mashhad. Moreover, by using a Cochran formula, the random sample consists of 384 people which comprise 52 percent men and 48 percent women. The target research group has been randomly selected from permanent and temporary housing which they lived in old to new housing. The advantage of conducting a questionnaire survey is that it helps to achieve “quantifiability and objectiveness” (Ackroyd and Hughes, 1981). The researcher-made questionnaire was structured into two sections. The first section is
about the physical dimension questions and the second section is about the environmental
dimension questions, so that, for analyzing the housing sustainability, 11 questions are related
to physical status and 10 questions related to environmental status. Also, the respondents were
asked to rate by using a five-point Likert scale (5 – too much, 4 – much, 3 – partly, 2 – little, 1 –
too little). To assess the validity of the questionnaire, the content validity ratio method has been
used and 15 university professors and urban experts in this region were selected. Experts rating
items into one of three categories: “essential,” “useful, but not essential” or “not necessary” (Ayre
and Scally, 2014). Then the responses are calculated in the following way: 

\[
CVR = \frac{(N_e - N/2)}{(N/2)}
\]

where \(N_e\) is the number of panelists indicating “essential” and \(N\) is the total number of panelists (Zamanzadeh et al., 2015).

\[
\text{Table I. Minimum values of CVR for different numbers of panelists}
\]

<table>
<thead>
<tr>
<th>No.</th>
<th>Minimum acceptable score for CVR</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.99</td>
</tr>
<tr>
<td>6</td>
<td>0.99</td>
</tr>
<tr>
<td>7</td>
<td>0.99</td>
</tr>
<tr>
<td>8</td>
<td>0.85</td>
</tr>
<tr>
<td>9</td>
<td>0.78</td>
</tr>
<tr>
<td>10</td>
<td>0.62</td>
</tr>
<tr>
<td>11</td>
<td>0.59</td>
</tr>
<tr>
<td>12</td>
<td>0.56</td>
</tr>
<tr>
<td>13</td>
<td>0.54</td>
</tr>
<tr>
<td>14</td>
<td>0.51</td>
</tr>
<tr>
<td>15</td>
<td>0.49</td>
</tr>
<tr>
<td>20</td>
<td>0.42</td>
</tr>
<tr>
<td>25</td>
<td>0.37</td>
</tr>
<tr>
<td>30</td>
<td>0.33</td>
</tr>
<tr>
<td>35</td>
<td>0.31</td>
</tr>
<tr>
<td>40</td>
<td>0.29</td>
</tr>
</tbody>
</table>

Source: Mohammadbeigi et al. (2015)
sustainability of housing. Moreover, physical dimensions as the physical symbol of housing are the most objective and materialist issues in assessments, analyzes and housing plans (Sartipipour, 2010). Table IV shows the components and items of the physical sustainability of housing. It includes 11 main components in the following sections: land area, durability of the materials and structure, life expectancy of housing, compatibility of residential units, suitability of the housing pattern with the needs of residents, visual quality, housing orientation, building permits, access to facilities and equipment, and housing plot size.

### 4.2.2 Environmental sustainability of housing

The environmental sustainability of housing is concerned with the impacts of housing on the environment and climate change, as well as the impacts of the environment on housing itself (Golubchikov and Badyina, 2012). Therefore, environmental protection should be thought of and be considered (Chen and Chambers, 1999; Ofori et al., 2000). In terms of environmental sustainability, housing construction should consider renewable energy, energy efficiency, water efficiency, ecology, conservation, material efficiency, air pollution, pollution control, indoor environmental quality, sustainable site, land utilization and management (Roufechaei et al., 2014). Table V shows the components and items of the environmental sustainability of housing. It includes ten main components in the following sections: sustainable construction materials, renewable energy, building national regulations in relation to energy, Indoor ventilation, non-degradation of natural resources, geographic conditions of the region, appropriate disposal of solid waste and sewage, health situation, housing green spaces, and water, electricity and gas services.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Cronbach’s α</th>
<th>No. of Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical sustainability</td>
<td>0.731</td>
<td>11</td>
</tr>
<tr>
<td>Environmental sustainability</td>
<td>0.804</td>
<td>10</td>
</tr>
</tbody>
</table>

**Table II.**
Calculating CVR of the research questionnaire

<table>
<thead>
<tr>
<th>Question number</th>
<th>CVR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
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</tr>
<tr>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>0.73</td>
</tr>
<tr>
<td>6</td>
<td>0.6</td>
</tr>
<tr>
<td>7</td>
<td>0.73</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>0.87</td>
</tr>
<tr>
<td>12</td>
<td>0.73</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
</tr>
<tr>
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<td>0.73</td>
</tr>
<tr>
<td>15</td>
<td>0.73</td>
</tr>
<tr>
<td>16</td>
<td>0.6</td>
</tr>
<tr>
<td>17</td>
<td>1</td>
</tr>
<tr>
<td>18</td>
<td>0.6</td>
</tr>
<tr>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>20</td>
<td>0.6</td>
</tr>
<tr>
<td>21</td>
<td>0.87</td>
</tr>
</tbody>
</table>

Source: Research findings

<table>
<thead>
<tr>
<th>Variables</th>
<th>Cronbach’s α</th>
<th>No. of Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical sustainability</td>
<td>0.731</td>
<td>11</td>
</tr>
<tr>
<td>Environmental sustainability</td>
<td>0.804</td>
<td>10</td>
</tr>
</tbody>
</table>

**Table III.**
Reliability test – Cronbach’s α

<table>
<thead>
<tr>
<th>Variables</th>
<th>Cronbach’s α</th>
<th>No. of Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical sustainability</td>
<td>0.731</td>
<td>11</td>
</tr>
<tr>
<td>Environmental sustainability</td>
<td>0.804</td>
<td>10</td>
</tr>
</tbody>
</table>

Source: Authors calculation by using SPSS
4.3 Conceptual framework

Based on the literature, goals and the measurements reviewed, the relationship between research components that to be measured in the form of a conceptual model of research is presented. The conceptual model is developed to explore the determinants of physical and environmental sustainability of housing in Region-one of Mashhad municipality. First, the dependent variable and then the independent variables are explained:

- Dependent variable: SH is the dependent variable in this analysis (Figure 2). As the above definition, SH plays an important role in the lives of the residents, pilgrims and tourists in the studied region.

- Independent variable: the independent variables are physical and environmental dimensions. As shown in Figure 2, the physical dimension includes 11 components and the environmental dimension also includes 10 components.

5. Result and discussion

5.1 SEM analysis result of SH

According to the results, 21 components of SH were summarized in two physical and environmental dimensions and was used as a second-order factor model. Figure 3 indicates

---

### Table IV. Components and items of physical sustainability of housing

<table>
<thead>
<tr>
<th>Components</th>
<th>Items</th>
<th>Indicator code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indicators of physical sustainability of housing</td>
<td>Compliance the land area with the needs of residents</td>
<td>A1</td>
</tr>
<tr>
<td>Durability of the materials in the residential unit</td>
<td>The durability of Foundation</td>
<td>A2</td>
</tr>
<tr>
<td></td>
<td>The durability of wall materials</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The durability of Base course</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The durability of roofing materials</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The durability of Flooring materials</td>
<td></td>
</tr>
<tr>
<td>Durability in structure</td>
<td>The durability of the housing skeleton</td>
<td>A3</td>
</tr>
<tr>
<td></td>
<td>The durability of Housing ceiling structure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Housing with anti-earthquake facilities</td>
<td></td>
</tr>
<tr>
<td>Life expectancy of housing</td>
<td>Compatibility degree of neighboring land uses</td>
<td>A4</td>
</tr>
<tr>
<td></td>
<td>Compatibility degree of roads</td>
<td>A5</td>
</tr>
<tr>
<td>Compatibility of residential units</td>
<td></td>
<td>A6</td>
</tr>
<tr>
<td>Suitability of the housing pattern (single unit, apartment, residential complex, High-rise building) with the needs of residents</td>
<td>The visual quality of housing</td>
<td>A7</td>
</tr>
<tr>
<td></td>
<td>The interior design quality of housing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The exterior architectural quality of housing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The durability of housing facade</td>
<td></td>
</tr>
<tr>
<td>Desired housing orientation</td>
<td>Appropriate orientation of housing in terms of cooling and heating load</td>
<td>A8</td>
</tr>
<tr>
<td></td>
<td>Appropriate orientation of housing for controlling and reducing sound</td>
<td></td>
</tr>
<tr>
<td>The number of residential units with building permits</td>
<td></td>
<td>A9</td>
</tr>
<tr>
<td>Easy access to facilities and equipment</td>
<td>Access to the Parking</td>
<td>A10</td>
</tr>
<tr>
<td></td>
<td>Access to the balcony</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Access to the storeroom</td>
<td>A11</td>
</tr>
<tr>
<td>Compliance the housing plot size with the needs of residents</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Source:** Research findings
the SH model in Region-one of Mashhad municipality in physical and environmental dimensions. In this model depending on the loading factors, it is determined which of the components are more important and have more significant effects on the sustainability of housing in the studied region.

The fit indexes results, reported in this SEM analysis, are $\chi^2$ statistics (CMIN) (Bt Wan Mohamed Radzi et al., 2017) and its ratio to the model degree of freedom (CMIN/df), the goodness-of-fit index (GFI), the adjusted goodness-of-fit index (AGFI) (Ren et al., 2018), parsimony-adjusted normed fit index (PNFI), parsimony-adjusted Comparative fit index (PCFI) (Schreiber et al., 2006) and root mean square error of approximation (RMSEA) (Zhang et al., 2016), as shown in Table VII. The generated result of SEM yielded the CMIN = 102.15, df = 42, CMIN/df = 2.431 and RMSEA = 0.056. According to the results in Table VII, the other reported indexes values are GFI = 0.90, AGFI = 0.80, PNFI = 0.648 and PCFI = 0.510 that have an acceptable fit for this model. Thus, it is concluded that the model is a suitable model with regard to these indexes values. Also, the present structured model describes that the data are appropriate where all the given $p$-values of the underlying structure were statistically highly significant at 0.001 (*** ) value and statistically significant at $\leq$ 0.05 value (Table VI). In addition, Table VI indicates that all components have a suitable critical ratio.

<table>
<thead>
<tr>
<th>Components</th>
<th>Items</th>
<th>Indicator code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of sustainable construction materials</td>
<td>The rate of utilization of recyclable building materials in the construction of housing</td>
<td>B1</td>
</tr>
<tr>
<td>Use of renewable energy in housing</td>
<td>The rate of using solar energy in a residential unit</td>
<td>B2</td>
</tr>
<tr>
<td>Observance of building national regulations in relation to energy Indoor ventilation performance</td>
<td>The rate of using double glazing windows</td>
<td>B3</td>
</tr>
<tr>
<td></td>
<td>The rate of using natural ventilation</td>
<td>B4</td>
</tr>
<tr>
<td></td>
<td>The rate of using mechanical ventilation</td>
<td>B5</td>
</tr>
<tr>
<td></td>
<td>The rate of using air conditioning</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The effect of the residential unit on the non-degradation of natural resources</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Correct orientation of the building</td>
<td>B6</td>
</tr>
<tr>
<td></td>
<td>The correct size of the window</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Appropriate disposal of solid waste and sewage of housing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The quality of the health situation in the housing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The rate of housing green spaces</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The rate of garden in housing</td>
<td>B7</td>
</tr>
<tr>
<td></td>
<td>The rate of greenhouse</td>
<td>B8</td>
</tr>
<tr>
<td></td>
<td>Quality of utilization of water, electricity and gas services</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The rate of garden in housing</td>
<td>B9</td>
</tr>
<tr>
<td></td>
<td>The rate of greenhouse</td>
<td>B10</td>
</tr>
</tbody>
</table>

Source: Research findings
(greater than 1.96) and ultimately have low standard error. As a result, the environmental and physical sustainability model of housing in this region is well-defined (Tables VI and VII).

The findings show that the quality factor of the health situation in the housing has the highest factor loading of 0.89 and more than other components, which has affected the stability of the studied housing. After that, the factor of observance of building national regulations in relation to energy is in the second rank, whereas, in contrast, the number of residential units with building permits by a factor loading of 0.35 is in the last rank. Ultimately, SEM indicates that the physical dimension with a factor loading of 0.72 has a higher effect on SH vs environmental dimension with a factor loading of 0.64. In other words, it is important to pay more attention to the environmental dimension of the housing in this region so that residents, pilgrims and tourists can experience more appropriate urban life.

6. Conclusion
This study was conducted in a central region of Mashhad, where, in addition to residents, millions of pilgrims and tourists use accommodation facilities and related services annually.
Therefore, the present research with using SH indicators as an essential tool has been considered for assessing the sustainability of housing in both physical and environmental dimensions. An attempt was made in this study to provide a valid and reliable model for measuring the effectiveness of physical and environmental factors on sustainability housing. SEM was analyzed in AMOS and described that the data were appropriate where all the $p$-value of all of the relationships were statistically significant and indicated less than 0.05. Thus, all the relationships between variables in the model were supported. According to the research results, the quality of health situation in the housing has the most factor loading. In contrast, the number of residential units with building permits is in the last rank; therefore, these two factors have the most and the least effectiveness on the sustainability of the studied housing.

To conclude, there should be an improvement in physical dimension for more unstable components, such as the number of residential units with building permits with supervision

Source: Research findings
of the Municipality over construction to prevent the creation of unauthorized housing in the region; durability in structure with using more resistant materials like metal; life expectancy of housing with renovation of old housing; easy access to facilities; and equipment with a standard interior design of housing. Then again, the environmental dimension of the studied housing requires more sustainability, including the rate of housing green spaces by creating a municipal incentive program that encourages residents to increase green space per capita in housing; the effect of the residential unit on the non-degradation of natural resources through preventing illegal luxury construction; and appropriate disposal of solid waste and sewage of housing through the implementation of waste separation at source by holding workshops for residents in the near future. Due to the factor loadings, it is concluded that

<table>
<thead>
<tr>
<th>Construct and variables</th>
<th>Standardized factor loading</th>
<th>Estimate</th>
<th>SE</th>
<th>CR</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical ← Sus_Housing</td>
<td>0.72</td>
<td>1.271</td>
<td>0.522</td>
<td>2.432</td>
<td>0.012</td>
</tr>
<tr>
<td>Environmental ← Sus_Housing</td>
<td>0.64</td>
<td>0.674</td>
<td>0.338</td>
<td>2.014</td>
<td>0.046</td>
</tr>
<tr>
<td>A1 ← Physical</td>
<td>0.73</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A2 ← Physical</td>
<td>0.51</td>
<td>3.473</td>
<td>1.446</td>
<td>2.402</td>
<td>0.016</td>
</tr>
<tr>
<td>A3 ← Physical</td>
<td>0.41</td>
<td>0.442</td>
<td>0.108</td>
<td>3.244</td>
<td>***</td>
</tr>
<tr>
<td>A4 ← Physical</td>
<td>0.46</td>
<td>0.512</td>
<td>0.112</td>
<td>4.710</td>
<td>***</td>
</tr>
<tr>
<td>A5 ← Physical</td>
<td>0.68</td>
<td>0.538</td>
<td>0.150</td>
<td>3.593</td>
<td>***</td>
</tr>
<tr>
<td>A6 ← Physical</td>
<td>0.84</td>
<td>1.344</td>
<td>0.135</td>
<td>8.663</td>
<td>***</td>
</tr>
<tr>
<td>A7 ← Physical</td>
<td>0.62</td>
<td>0.522</td>
<td>0.385</td>
<td>2.004</td>
<td>0.036</td>
</tr>
<tr>
<td>A8 ← Physical</td>
<td>0.54</td>
<td>0.289</td>
<td>0.119</td>
<td>2.427</td>
<td>0.015</td>
</tr>
<tr>
<td>A9 ← Physical</td>
<td>0.35</td>
<td>0.710</td>
<td>0.239</td>
<td>3.074</td>
<td>0.003</td>
</tr>
<tr>
<td>A10 ← Physical</td>
<td>0.49</td>
<td>0.547</td>
<td>0.118</td>
<td>4.620</td>
<td>***</td>
</tr>
<tr>
<td>A11 ← Physical</td>
<td>0.80</td>
<td>1.277</td>
<td>0.524</td>
<td>2.437</td>
<td>***</td>
</tr>
<tr>
<td>B1 ← Environmental</td>
<td>0.78</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B2 ← Environmental</td>
<td>0.68</td>
<td>0.839</td>
<td>0.114</td>
<td>7.382</td>
<td>***</td>
</tr>
<tr>
<td>B3 ← Environmental</td>
<td>0.87</td>
<td>1.137</td>
<td>0.125</td>
<td>9.119</td>
<td>***</td>
</tr>
<tr>
<td>B4 ← Environmental</td>
<td>0.72</td>
<td>0.676</td>
<td>0.336</td>
<td>2.013</td>
<td>0.044</td>
</tr>
<tr>
<td>B5 ← Environmental</td>
<td>0.47</td>
<td>0.742</td>
<td>0.128</td>
<td>5.780</td>
<td>***</td>
</tr>
<tr>
<td>B6 ← Environmental</td>
<td>0.61</td>
<td>1.304</td>
<td>0.164</td>
<td>7.530</td>
<td>***</td>
</tr>
<tr>
<td>B7 ← Environmental</td>
<td>0.56</td>
<td>0.666</td>
<td>0.106</td>
<td>6.256</td>
<td>***</td>
</tr>
<tr>
<td>B8 ← Environmental</td>
<td>0.89</td>
<td>3.214</td>
<td>1.325</td>
<td>2.421</td>
<td>***</td>
</tr>
<tr>
<td>B9 ← Environmental</td>
<td>0.38</td>
<td>0.586</td>
<td>0.123</td>
<td>2.905</td>
<td>0.044</td>
</tr>
<tr>
<td>B10 ← Environmental</td>
<td>0.80</td>
<td>1.529</td>
<td>0.171</td>
<td>8.902</td>
<td>***</td>
</tr>
</tbody>
</table>

Note: The CR (critical ratio) is the commonly recommended basis for testing statistical significance of SEM components with CR values greater than 1.96, establishing significance at $p < 0.05$ level

Source: Research findings

<table>
<thead>
<tr>
<th>Name of index</th>
<th>Yielded value</th>
<th>Level of acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMIN</td>
<td>102.15</td>
<td>$2df \leq \chi^2 &lt; 3df$</td>
</tr>
<tr>
<td>df</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>CMIN/df</td>
<td>2.431</td>
<td>$2 \leq \chi^2/df \leq 3$</td>
</tr>
<tr>
<td>GFI</td>
<td>0.90</td>
<td>$0.90 &lt; GFI \leq 0.95$</td>
</tr>
<tr>
<td>AGFI</td>
<td>0.80</td>
<td>$0.85 &lt; AGFI \leq 0.90$</td>
</tr>
<tr>
<td>PNFI</td>
<td>0.648</td>
<td>$\geq 0.6$</td>
</tr>
<tr>
<td>PCFI</td>
<td>0.510</td>
<td>$\geq 0.5$</td>
</tr>
<tr>
<td>RMSEA</td>
<td>0.066</td>
<td>$0.05 \leq RMSEA \leq 0.08$</td>
</tr>
</tbody>
</table>

Source: Research findings and source of the level of acceptance: Gholami and Khalaji (2017)

Table VI. Parameter estimates and standardized factor loading of SEM of SH

Table VII. The SH adaptations model fit and their level of acceptance

of the Municipality over construction to prevent the creation of unauthorized housing in the region; durability in structure with using more resistant materials like metal; life expectancy of housing with renovation of old housing; easy access to facilities; and equipment with a standard interior design of housing. Then again, the environmental dimension of the studied housing requires more sustainability, including the rate of housing green spaces by creating a municipal incentive program that encourages residents to increase green space per capita in housing; the effect of the residential unit on the non-degradation of natural resources through preventing illegal luxury construction; and appropriate disposal of solid waste and sewage of housing through the implementation of waste separation at source by holding workshops for residents in the near future. Due to the factor loadings, it is concluded that
the environmental dimension should be improved further than the physical dimension. Consequently, urban planners should focus more on adopting policies to improve the environmental components of the housing. According to the research findings, Mashhad Municipality can formulate various policies to improve the sustainability of housing. In addition to educating residents about the benefits of SH, the municipality can use obtained sustainability components of this research to evaluate the performance of all housing in Mashhad. Moreover, with a large enough number of housing units assessed, residents are encouraged with more confidence in increasing green space (e.g. creating green roofs and green walls) and renovating old houses. Also, the results of this research could be generalized to Land and Housing Organization of Mashhad City, Mashhad Municipality and City Council of Mashhad as well as other planner and researchers in this field. Besides, findings should be of interest to all segments of the Construction and Consultant Engineers Companies. The findings are significant as it focuses on identifying SH components in Region-one of Mashhad at a time when the city experiences huge development in the housing construction due to huge population attraction, which has so far not paid attention to its sustainability. Also, there is an urgent need for renovation of old housing in the city as the Municipality has been criticized for allowing to private developers for economic reconstruction not sustainable.

This study has some limitations. A part of the approach of the study was based on a structured questionnaire survey which some residents avoid to fill out a questionnaire – some even have thought they have encountered by a salesperson. Another important limitation is the authors were not able to arrange an interview with any specialists at Land and Housing Organization of Mashhad City for CVR method. To mention the research limitation, economic and social dimensions were not examined in the present research; hence, it is recommended to study these factors in future investigations on account of their significance.

References


Further reading


About the authors

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