Regulating natural resource consumption in the construction sector using emery model

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Abstract. The rising demand for infrastructural facilities and housing units across the world has resulted in increased pressure on environment due to the uncontrolled and unregulated exploitation of natural resources. A sustainable resource use framework for the construction industry is essential to ensure the regional economic progress without compromising environmental sustainability. Judicious regulation of the resource use is possible only through evolving appropriate parameters to represent the resource consumptive pattern that could be used both by the planners and the regulators. In this connection, several tools and techniques have emerged that are used to assess the resource use and suggest both the economic and environmental implications of the material choice. Among them, emery analysis has been successfully used to understand the current state of resource use and its associated impacts on the environment. The current form of emery based descriptions are independent of the time scale and hence a real-time evaluation of the impact of material use often turns out to be unsuccessful. The environmental damages that are reported in these regions are often due to the uncontrolled rate of extraction and the emery evaluations need to incorporate the rate of extraction of resources across different time scales. An approach to estimate the emery at different time scales based on the prevailing consumption rates is proposed in this paper which would enable the regulators/planners to assess the current resource use pattern and suggest alternate pathways of material use to ensure the sustainability of construction sector.

1. Introduction
About 30–40% of the total natural resources used in industrialized countries are exploited by the building industry and of this, about 30% of energy use is accounted for housing development [1]. Thus, consumption of resources by the construction sector has indirectly contributed to innumerable environmental issues like over use of non-renewable energy, over-exploitation of materials, exhaustion of resources, wastage of energy, global warming, abiotic depletion and higher toxicity potentials [1, 2]. Uncontrolled extraction of natural resources from their places of origin has resulted in severe environmental problems. This in turn, raises a significant challenge to sustainability of building materials across the globe as majority of these are procured directly from natural deposits. Available reports say that construction industry uses more raw materials than any other type of industry [3]. Thus the environmental pressure that prevails at regional level is very high to support the building industry. The recent occurrence of floods which caused large scale destruction especially in Kerala is attributed directly to the uncontrolled consumption pattern of natural resources such as quarrying, and changes to the natural landscape brought about in the name of development. Also, over this time period, several laws and regulations were implemented to control the mining of sand. The demand for aggregates to support the construction sector have compelled the builders to shift to manufactured sand which too aggravated
the prevailing problems. Along with that, direct procurement of materials from nature is curtailing the alternate mechanisms for resource supply which also has to be resolved. These call for immediate action, and a curb on unregulated alteration to the nature has to be enforced for ensuring the sustainable extraction of resources. But often, scientific approach to regulating the resource use is a major bottleneck in the implementation process.

It was identified that thermodynamic analysis can be used in defining environmental sustainability which, in turn, can be applied to the buildings also [4]. A wide variety of tools like energy analysis, ecological footprint analysis, life cycle analysis, exergy analysis, emergy analysis etc. are available for evaluating the material and energy requirements of these thermodynamic engines [1]. However, only emergy analysis tool is able to provide a comprehensive environmental analysis as most other tools donot consider adequately the contribution of biosphere in the formation and concentration of resources [5]. Emergy analysis has been used widely to evaluate various types of systems such as geographical regions, food production, industrial processes, buildings etc.[6].

1.1. Emergy analysis

Emergy is the memory of all energies that are used directly and indirectly to make a product or for providing a service. In emergy analysis, the earth is considered to be a closed system with solar energy, deep earth heat and tidal energy as the major constant energy inputs. It is assumed that all living systems sustain one another by participating in a network of energy flow and its conversion into both higher quality energy and degraded heat energy [7]. It is a concept which unifies different forms of energy required in varying quantities in the production of a material/service. It is based on the assumption that everything can be expressed in terms of equivalents of solar energy as solar energy is the main energy input to the earth. This approach values the goods and services from the environment, society and the economy by expressing them in solar emjoules (sej). While the unit, joule is able to convey only the amount of available energy that can be used in the present, the unit emjoule is able to convey the directly and indirectly used energies in the past to produce something [8]. This can then be used for computing the ‘transformity’ for the resource expressed as solar emjoule per joule, which is the total emergy used for producing unit energy i.e., the emergy needed to obtain 1 J of a product or service, directly or indirectly (sej/J) [9, 10]. From this, the total solar emergy of a product can be estimated using equation 1,

\[ U = \sum_{i=1}^{n} E_i \times T_i \]  

where \( U \) is the total emergy calculated over all independent input flows, \( E_i \) is the available energy or exergy, and \( T_i \) is the solar transformity of the \( i^{th} \) input flow of a product or service. The same item can have varying values of transformity depending upon which system produced it. Some times, it is convenient to use emergy per unit, such as quantity, mass, etc. to transform the accounted quantities in emergy [11]. In order to avoid the time consuming process of computing the transformities each time, unit emergy values reported in the earlier studies are used [12, 10]. As it is possible to express all goods and services from the environment, society and economy in units of emergy, it is possible to directly compare and assess the condition and sustainability of a system and also provide the policy-makers with a valuation system for managing the human and natural environments in a better manner [8].

2. Methodology

Building data for the past 25 years from 1994 to 2018 from an environmentally fragile zone in Kerala, Wayanad district was collected for assessing the sustainability aspect of the construction pattern in the study area. One house was chosen randomly for representing the construction pattern prevailing in the study area each year. Only single and double storeyed residential buildings were considered for the analysis. The sample data for residential buildings were collected from the building planners and engineers in the study area. The cost of building materials for various districts of Kerala for the last
25 years were collected from the records kept at Economics and Statistics department, Government of Kerala [13]. The flow chart of the methodology adopted is given in Figure 1.

![Flow chart of study methodology](image)

**Figure 1.** Study methodology

### 2.1. Systems diagram
The resource flow pattern in the construction of residential units is represented using systems diagram for providing an overview of the scope and boundaries considered in the analysis. Energy pathways shown in Figure 2 represent all driving energies of the materials and their interactions within the system. The systems diagram is prepared using standard systems language symbols. In this, both industrially produced materials and naturally procured materials flow into the building system and the waste generated goes to the energy sink. It also shows the energy and material inflows and outflows of a system. The services were not included in this study as it has been identified that human labour and services would not significantly influence the unit emergy values for materials and buildings [14]. The emergy analysis has been carried out using the available unit emergy values (UEV) from literature [2, 15, 16, 17, 18, 19] and the results obtained has been analyzed to compute the emergy values of the building components.

### 3. Results and discussion

#### 3.1. Emergy of materials used
Figure 3 depicts the weighted emergy value of building materials estimated using the data collected from buildings constructed across 25 years. Among the materials, sand being naturally available, is expected to have low emergy value, but showed the maximum value of emergy which may be attributed to its increased contribution in building construction. This can be considered as a pointer towards the
shift towards alternate materials such as manufactured sand. Wood is found to have the least value when compared to other materials which can be attributed towards its minimal contribution in building construction. But the shortage of wood has led to mechanized procedures and search for alternate materials. This has lead to the replacement of wooden doors and windows with newer materials like steel, cement concrete, and PVC based openings.

3.2. Emergy per unit cost of materials
The trend lines for industrially produced materials and for naturally procured materials for the last 25 years are given in Figure 4 and Figure 5 respectively in order to understand the variation of emergy per unit cost of materials and the variation in total construction cost of buildings.
3.2.1. Industrially produced materials
From Figure 4, it is clear that the total building construction cost per square metre shows an exponential increase while the slope of emergy per unit cost is showing a declining trend. There is a sudden decline in the trend of emergy per unit cost of brick and cement beyond 2015 which is due to the fact that there is not much variation in the prices between consecutive years. Industrial materials have high emergy, but the fluctuations are contained through the pricing mechanism. As selection of materials with high emergy per unit area takes place with increase in the purchasing power of people, the construction cost of building also escalates.

3.2.2. Naturally procured materials
Figure 5 depicts the change in emergy per unit cost of naturally procured materials and the building construction cost. There is a sudden decline in the trend of emergy per unit cost of rubble, sand and wood beyond 2015 which can be attributed to a decline in the rate of cost escalation of these materials except for gravel. This declining trend in the steadily increasing cost of sand and wood can be attributed to the development of alternative materials replacing the conventional river sand and natural wood. Gravel continues to be in demand and its cost is increasing at a steady rate as no new alternate materials could be identified for replacing it. Total building construction cost per square metre shows an exponential increase while the slope of emergy per unit cost is showing a declining trend. Even though naturally procured materials are at a lower emergy level initially, as each year progresses, the resource supply diminishes thereby creating a cost barrier. This will make the resources which were procured naturally in the initial stages to become a produced material as any other industrial material. So if it is possible to regulate the price of natural materials in a judicious manner, higher consistency can be achieved.

3.3. Variation of emergy with material
Figure 6 shows the variation of emergy for the materials used for walls and floors across 25 years. It could be observed that a wide variety of materials were evolved as flooring materials including plain cement concrete, red oxide, mosaic, ceramic tiles, granite and vitrified tiles. It is observed that mosaic is having the least material emergy whereas cement concrete flooring has the maximum material emergy. It could also be observed that the material emergy for flooring materials has reached a nearly steady state. It could also be observed that brick remains the most widely used material for the construction of walls.

3.4. Spatial variation of emergy
Figure 7 and Figure 8 gives the variation of emergy per unit cost of industrially produced materials, i.e., steel and cement across five selected districts of Kerala, Thiruvananthapuram(TVM), Kottayam(KTYM),
Figure 6. Variation of emergy with varying material choices

Figure 7. Variation of emergy per unit cost of steel at various locations.

Figure 8. Variation of emergy per unit cost of cement at various locations.

Thrissur (TCR), Kozhikode (KKD) and Kannur (KNR). Figure 9 and Figure 10 gives the variation of emergy per unit cost of naturally procured materials i.e., wood and sand at the five selected districts in Kerala. The objective of this plot is to demonstrate how emergy values of industrially produced materials and naturally procured materials could be affected by the location of its supply. It is clearly visible from Figure 7 and Figure 8 that the emergy per unit cost of industrially produced materials are nearly constant irrespective of the place of its supply and use. From Figure 9 and Figure 10, it could be observed that the emergy per unit cost varies considerably with change in its location of use. Thus, it could be inferred that for naturally procured materials, the location of its supply and use has a significant effect on the emergy per unit cost of the material. The materials that are locally sourced, like sand, building stones etc. are more sensitive to their source when compared with industrially manufactured products like steel, cement,
etc. Thus the effect of spatial variation on emergy per unit cost of materials also should be considered while using emergy as a parameter for regulating the use of resources for construction.

![Figure 9. Variation of emergy per unit cost of wood at various locations.](image1)

![Figure 10. Variation of emergy per unit cost of sand at various locations.](image2)

**4. Conclusion**

The utility of using emergy as a parameter for regulating the resource use has been established in this paper. It is identified that the materials which are naturally procured have significant spatio-temporal influence on the emergy values. Such a pattern is not prominent among the industrially produced materials. Thus the need for regional specific evaluation on the environmental controls on the resource procurement seem to be undertaken to forecast any unexpected regulations on their procurement. Thus, the need for refining the emergy values corresponding to the time and location aspects is also demonstrated here. This would enable policy makers, engineers and regulators to understand the impact of prevailing resource use pattern and propose better options for its use.

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