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Original Paper

Circular Economy and Eco-Innovation Solutions for Low-Carbon Buildings in Cities: The Case of Kayseri

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Abstract

An analysis of eco-innovations solutions for efficient low carbon buildings through circular economy principles (reduce, reuse, recycle), that also consider economic and social indicators has been performed at the national (Turkey) and urban scale (Kayseri). The framework for the city of Kayseri and the implementation of the circular economy for construction chain were determined that the three enabler tools which are policies, funding and awareness and collaboration could help to implement circular city model in Turkey. Reducing energy intensity and understanding the factors that can influence this (such as urbanization and industrialisation) will help mitigate future climate changes, improve local air pollution and health.

Keywords

built environment, circular economy, cities, resource productivity, sustainable development

1. Introduction

Industrial activities provided better living conditions and higher economic conditions; however, they also created negative impacts on the environment (Wu, 2014, p. 5). Globally growing population brought high material consumption, waste and pollution. Therefore, during the last century, countries have been trying to create a sustainable development and minimise the environmental impacts of existing progress. To achieve this, circular economy could play a key role.

The circular economy term has been introduced in the 1960s, and benefit from “reduce, reuse and recycle” principles (Du, 2016, p. 71). The concept tries to use higher material circulation and lower energy consumption through imitating nature. However, it is not only an economic activity but also a social and environmental task to create activities for people and protect the environment. Pearce and Turner (1990, cited in Heshmati, 2015, p. 2) described the theory between environment and economics, concluded that they are both linear or continuing system without recycling options; therefore, ignoring the environment causes ignorance in the economy.

Resource productivity has become more important for economics and policies because efficient material usage will help to save energy and purchasing cost (Bleischwitz, 2010). Reduction in the material resources and rapid increase in environmental problems created the action for recycling policies in Europe (Heshmati, 2015). Germany leads this implementation of circular economy principle through the closed cycle waste management system. Netherland also proposed certain incentives and install the framework of circular economy in their political systems. Bleischwitz (2010, p. 228) indicates that resource productivity based policies could help to transform our existing system to low carbon economy.

The built environment has a direct connection between natural environment, economic activities and social well-being (Figure 1). On the other hand, the built environment has a significant role on the consumption side of the materials, through consuming the materials and producing demolition waste (Arslan et al., 2012, p. 313).

In the existing worldwide linear economic system, waste prevention and recycling activities coincide with circularity; however, circular economy demands a wider approach to the whole system instead of small loops in the sectors (Van Eijk, 2015, p. 3). Circularity provides longer lifetimes for materials through eco-innovations not only in technology but also in social and cultural knowledge. Therefore, a collaboration between all players which are government, stakeholders, companies and research institutes is necessary in order to have an integrated system.

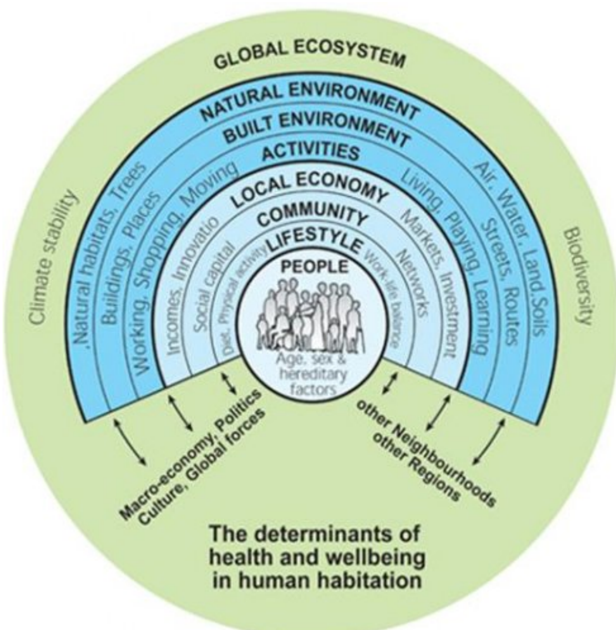

Figure 1. The Relation between Natural Environment and Built Environment (Bath & North East Somerset Council, 2016)

This paper aims to investigate the circular economy principles and how they can be adopted to achieve a low carbon built environment in cities through identifying the current construction sector by proposing a circular chain for all sectors and actors. The case study of Kayseri City has been chosen because several urban renovation projects take place and this study may help to provide insight into future actions and other case studies worldwide.

2. Why Cities Matter?

In the world, 40% of raw materials have been used by buildings during the construction process (Friends of the Earth, 2009, p. 21, cited inBaker-Brown, 2017, p. 15). On the other hand, construction sector plays a significant role. For example, in the UK, this sector produces nearly 60% of the UK's total waste in 2014 (DEFRA, 2016, p. 1).

Modern cities currently use linear metabolism which does not take into account the impact of materials use and waste production (Girardet, 2010, p. 10). Consumer goods are created from raw materials and become waste at the end of the lifecycle (ibid). Energy is created from fossil fuels and the gas emissions are released into the atmosphere (ibid). Food waste, on the other hand, is discharged from farmlands (ibid). Circular metabolism, however, aims to create a more sustainable environment for food, energy and material production (Figure 2). European Environment Agency (EEA, 2016, cited in Elia et al., 2017, p. 2374) has introduced five steps of the circular economy in a recent report:

a. Reducing the amount of input and conserving natural sources;

b. Reducing emissions especially coming from fossil fuels;

c. Reducing material and energy losses through recycling and reusing;

d. Reducing fossil fuels and increasing renewable energy share in generation;

e. Increasing the value of products through business models.

These steps will provide sustainable food, energy and material cycles. Circular cities also achieve certain economic goals such as economic growth, material cost savings, job creation and innovation based materials (EMF, 2015, p. 11). A recent study has been carried in seven EU countries by Club of Rome (2015, cited in Baker-Brown, 2017, p. XV) illustrates that changes from linear to the circular economy can provide 70% reduction in Green House Gas (GHG) emissions and 4% enlargement in labour force in national scale. Companies and citizens can benefit from this system environmentally and economically with the help of this change (ibid).

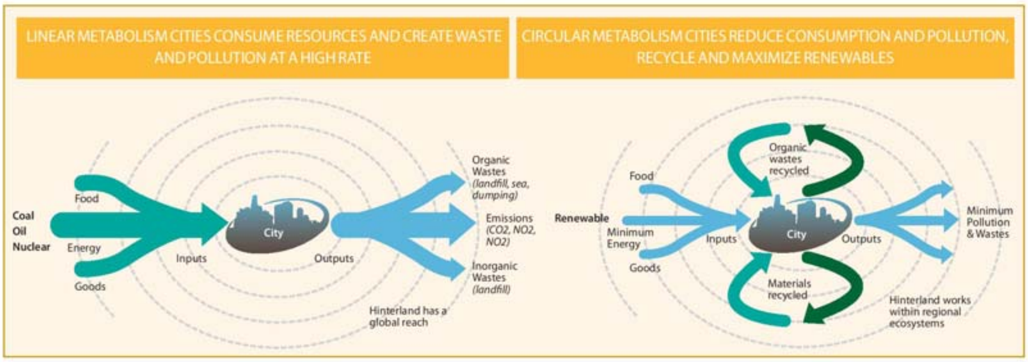

Figure 2. Linear and Circular Metabolisms for Cities (Girardet, 2010, p. 11)

As a result, background information indicates that increasing population causes a parallel trend for construction activity and energy demand. Therefore, changing the traditional development activities to circular methods could create a closed loop for the necessary needs of the cities. Circular economy implementations and circular city models could be the solution of high energy intensity in low-carbon built environment and construction material sector.

3. Circular Economy-Methodological Approaches and Studies

3.1 Methodological Approaches

Evaluation of the circular economy has several research methods such as Life Cycle Assessment (LCA), Material Flow Analysis (MFA), linear and non-linear programming techniques, input and output analysis, etc. (Wu, 2014, p. 15). It is important to understand these research methods in order to evaluate implemented circular economy examples.

LCA includes the complete life cycle of products starting from raw material extraction until final waste disposal (Wu, 2014, p. 15). Manufacturing, transportation and selling processes are also included in the LCA method. It evaluates the product life in terms of outputs and environmental impacts. ISO14000 standards have been introduced for environmental management by International Organization for Standardization (ISO) in 1993. LCA described in the standards as several methods in order to evaluate the environmental impacts of the products or services. Directly related material and energy flows to the products and services are also included in the entire life cycle assessment. ISO has developed a four-phase framework for LCA standards named ISO14040 since 1997.

Linear Programming (LP) technique refers to evaluate different circulation systems in complicated production (Wu, 2014, p. 15). LP method was used in the United States to optimize the efficiency of labour and energy in steel sector by Hannon and Brodrick (1982, cited in Wu, 2014, p. 16). The impacts of the paper life cycle in London and the circulation problems of pulp and paper sector in Europe, additionally, were analysed with LP model. The Linear model is an easy method to evaluate static situation; however, it is difficult to use it when the prediction of the time is included in the dynamic optimization.

Nonlinear and dynamic models have also been used since 1995 to evaluate characteristics of emissions, environmental policy of the raw materials, energy under MFA conditions and energy requirements of different dynamic evaluation techniques by several researchers (Wu, 2014, p. 16). However, a dynamic nonlinear material circulatory system model with LCA and MFA method still needs further research.

Useful energy analysis has developed to evaluate the balance of useful work of the material and energy flow and the reference environment. It calculates the conservation of mass and energy and the first and second law of thermodynamics. The technique identifies the entire waste and energy process to achieve efficiency and reduce the inefficiencies in the system.

These evaluation techniques and methods have been used for a long time; however, implementation of these models is quite complicated. Therefore, reviewing several empirical studies could help to understand the framework of the circular economy principle (Table 1).

Each method has their own flexibility and limitations. Integration of methods and modelling tools can support decision making at all levels (Spataru, 2018). Adopting an integrated approach will help the transition towards a circular economy to meet SDGs (ibid).

Table 1. Selected Analytical Methods with Potential Application to Circular Economy

	Method	**Brief description**	**Relevance to the circular economy**	**Example of studies**
1	Analytic Hierarchy Process (AHP)	A technique for complex processes	More organised approach for all parties	Sizhen *et al.*, 2005
2	Full Permutation Polygon Synthetic Indicator (FPPSI)	An iterative calculation method		Li *et al.*, 2009
3	Data Envelopment Analysis (DEA)	A performance measurement technique		Liang and Wang, 2011
4	Weighted sum model	An evaluation method for single dimension criteria		Li and Su, 2012
5	Life Cycle Assessment (LCA)	Quantitative assessment method provides environmental impacts of a products life		Zhang, Ma and Wang, 2012
6	Circular Economy Efficiency Composite Index (CEECI)	A benchmarking method		Ma *et al.*, 2014
7	Substance Flow Analysis	Quantifies flows and	Indication of	Wen and Meng, 2015

	(SFA)	stock substances	substance rates	
8	Resource Productivity (RP)	An indicator showing material production and consumption proportion		Wen and Meng, 2015
9	Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM)	A characterisation method for socio-economic systems	Indication of material efficiency	Lu *et al.*, 2016
10	Construct Indicators and Measurement Model	An approach to measuring circularity		Huilu *et al.*, 2016 Ellen MacArthur Foundation, 2015a
11	Material Flows Analysis (MFA)	Quantifies flows and stock materials	Indication of material and waste rates	Sun *et al.*, 2017

3.2 Circular Economy Studies

Circular economy studies have recently increased worldwide. The first Circle City Scan report was developed for the city of Amsterdam (Circle Economy, 2016). This report indicates that 70,000 new homes will be created and 3% productivity increase worth 85 million euro per year will be achieved by 2040. Low and medium-skilled employment opportunities will exist with the help of productivity increase. Half a million tonnes reduction per year in CO_2 emissions has been estimated. All these results have been built on strategies in construction chain. In London, on the other hand, a circular economy has been developed for Old Oak and Park Royal (ARUP, 2015). Strategies have been identified in order to create 25,000 homes and 65,000 jobs in these sites. Different supporting systems have been identified for the operation of the circular system (
Table **2**).

Table 2. Strategies Adopted for Case Studies

Case Study	Strategies Adopted
Shanghai Circular Economy Study[1]	**1) Technical Supporting System** - Promoting the development of technology - Promoting the technological transformation through industry - Developing the technological system through assessment methods - Technology exchange **2) Policy Supporting System** - Proposing policy mechanisms for circular economy - Raising awareness about circular economy and effective material consumption in public buildings via government - Mobilizing the functions of local government - Enhancing market mechanism **3) Economic Support System** - Constructing green fiscal accounting systems - Providing financial support and tax relief to encourage the use of renewable resources
Old Oak & Park Royal/London: A Vision for a Circular Economy[2]	**1) Resilient:** Reliable, flexible and integrated system **2) Optimised:** Capturing and reusing the material waste **3) Social:** Collaborative interaction with business and society **4) Renewable:** Secure, affordable and renewable energy **5) Valuable:** Enhancing financial, social and environmental outcome **6) Accessible:** Convenient and rewarding service life **7) Shared:** Sharing ownership, use and activities **8) Systematic:** Enabling systematic eco-innovations
Circular Amsterdam[3]	**1) Smart Design:** Modular and adaptive design for the purpose change of buildings so materials can be reused. **2) Dismantling and Separation:** Enabling dismantling and separation of construction waste. **3) High-value Recycling:** Efficient reuse of construction materials. **4) Marketplace and Resource Bank:** Resource exchange in the market to reuse materials in new buildings.

Sources: [1]Wu, 2014; [2]ARUP, 2015; [3]Circle Economy, 2016.

4. Method

The main aim of this research is to determine which circular economy principles can contribute to sustainable development in cities. In order to achieve this, a theoretical model has been developed. The theoretical model has been constructed based on lessons learnt from the circular case study of Amsterdam (Circle Economy, 2016), is known as the front-runner in circularity and acting as a pilot case study in several programs. The theoretical model has been applied to Kayseri, a city in transition, which faces significant changes and has strong plans for regeneration. The three dimensions considered in order to establish the framework of the circular city are economic, environment and society.

Following the analysis on indicators, it was determined that the most effective indicator of circular city model is construction chain, therefore the circular city model has been built on this sector. Circular construction chain model has been divided into four main concepts (smart design, deconstruction and separation, high-value recycling and reuse and marketplace and resource bank) (Figure 3).

Figure 3. Main Concepts for the Circular Construction Chain Model

Each concept has been then categorised in sub-sections in order to give detailed information of flexible design, implementation of innovative technologies, options for better reuse, recycle, waste separation. The concept has been tested for a case study, Kayseri, and this is discussed in section 5.

5. Case Study—City of Kayseri, Turkey

5.1 Choice and Motivation

Turkey has a population of 80 million (the year of 2016) (Figure 4). Future projections illustrate that population will reach 95,000,000 in 2050; although, the growth rate has been decreasing during the last few decades (The World Bank, 2017). Cities have seen significant growth, with Istanbul being the most populated city in Turkey with a population of 14.8 million (TurkStat, 2016). The same growth trend has been seen in Ankara and cities located on the coast (Figure 5).

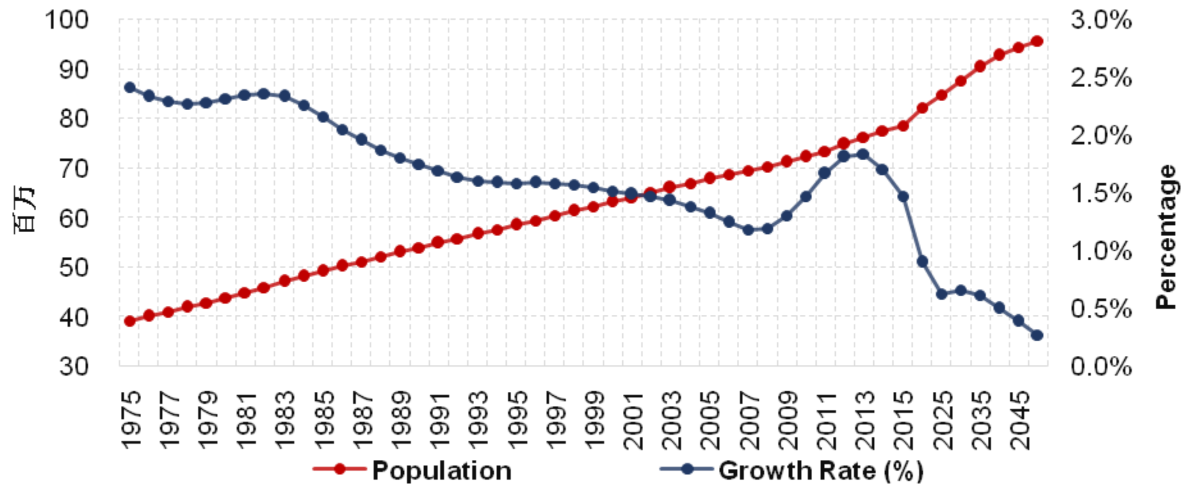

Figure 4. Turkey's Population Trend between 1975-2045 (Data Source: TurkStat, 2016)

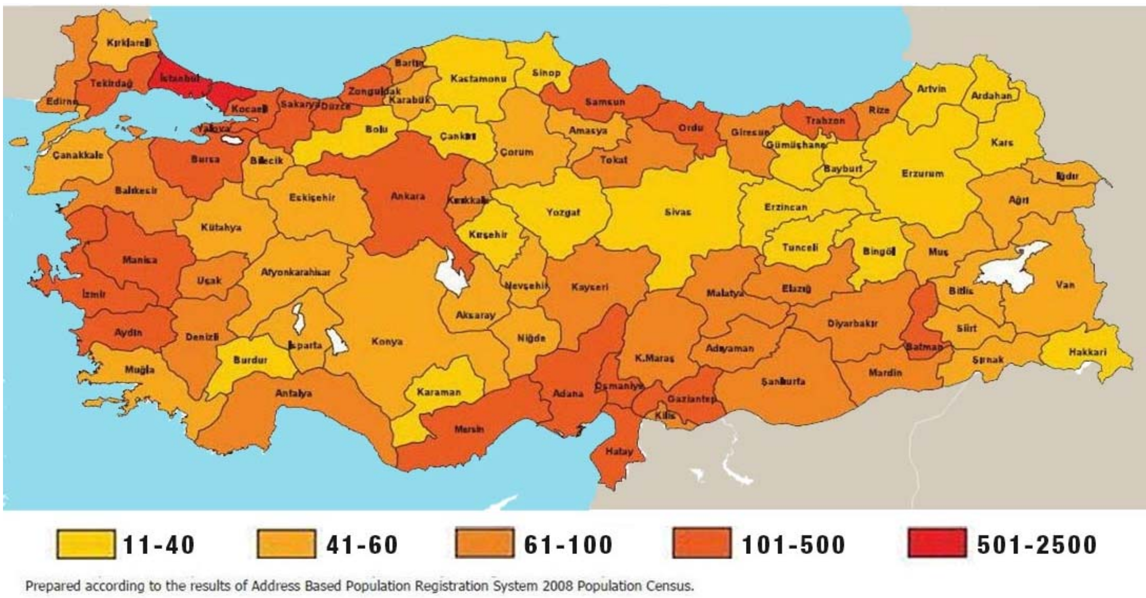

Figure 5. Population Density Map of Turkey according to 2008 Data (EEA, 2015)

The Turkish economy has been expanded continuously during the last few decades; even though, several economic crises hit the world (Rawdanowicz, 2010, p. 5). These economic crises have affected Turkish economy in short term, and reforms have helped to start disinflation (ibid). After 2000, average GDP growth was 5% and current GDP is 858 USD Billion (The World Bank, 2017) (Figure 6). However, growth has slowed down after 2012. New economic, social and political needs have been created by 3 million Syrian refugees (The World Bank, 2017). Elections in 2015 and an attempted coup in 2016 have delayed private investments and reforms. Tourism and foreign investment, on the other hand, have reduced because of several terrorist attacks. Turkey's dependency on energy and raw material imports, political instabilities, increased population and other factors which have been discussed have caused fluctuation in GDP growth.

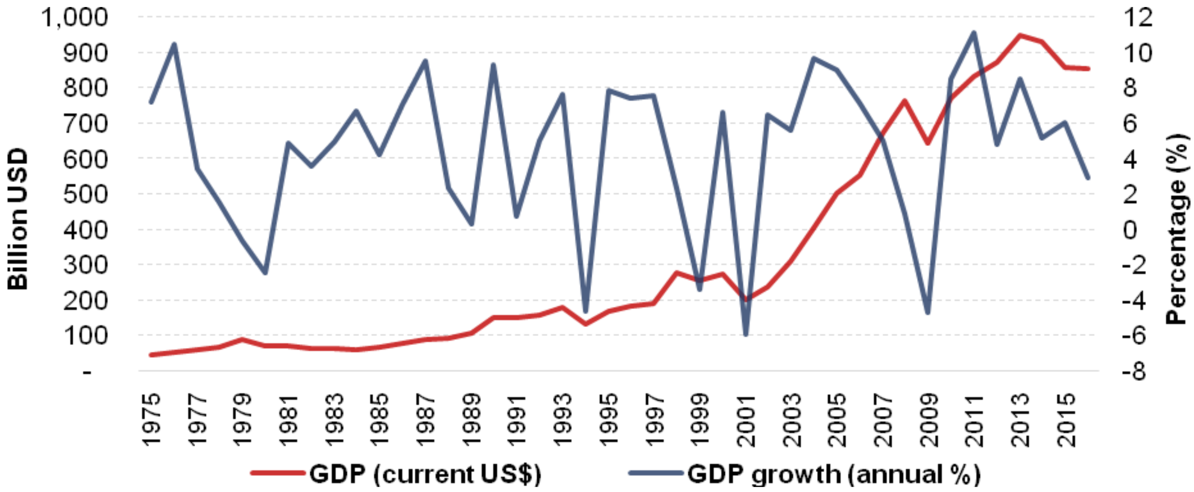

Figure 6. Economic Indicators of Turkey (The World Bank, 2017)

The service sector is the main economic activity with 65.0% of GDP share. Industry and agriculture are the other sectors with 26.5% and 8.5% respectively (Statista, 2015). Turkey's imports of industry and energy have increased more than exports since the 1940s, therefore, the foreign trade gap has been increasing (Sonmez, 2015). High raw material and energy imports, creates more fragile and unstable economy. Therefore, actions related to energy and resource productivity needs to be taken in Turkey.

Construction sector in Turkey is one of the main drivers of the economy including cement, iron and steel production. Moreover, most of the existing building stock in Turkey needs either renovation or demolition because of high earthquake risks. Therefore, circularity in the construction sector is significant by not only providing resource efficiency but also using recycle and reuse activities through the better waste management system.

From the targets set by the Turkish Government to reduce energy demand, the key one is 25% of building stock in 2012 should be converted to sustainable building by 2023. This target could only be achieved through eco-innovation solutions on different scales (material, building, neighbourhood, city, region and country). One way to achieve these targets is to implement circular economy principles in each scale and consider the following five steps:

a. Reducing the amount of input and conserving natural sources;

b. Reducing emissions especially coming from fossil fuels;

c. Reducing material and energy losses through recycling and reusing;

d. Reducing fossil fuels and increasing renewable energy share in generation;

e. Increasing the value of products through business models.

5.2 Key Findings from Data Analysis

Turkey has an increasing energy demand for years because of the growth in population and economic developments (GDRE, 2012, p. 2). The energy consumption in the industry has increased by 413% since 1975 and by 191% for residential-commercial and public services. Cement, iron and steel industries consume nearly 45% of total industrial energy demand. The energy consumption of these construction-related industries has been increasing since 1975 (Figure 7); although, there has been a drastic decrease in 2000 because of economic recession. The number of new buildings has also the same trend during the same period (Figure 8). It can be seen that the number of constructed buildings has also reduced after 2000.

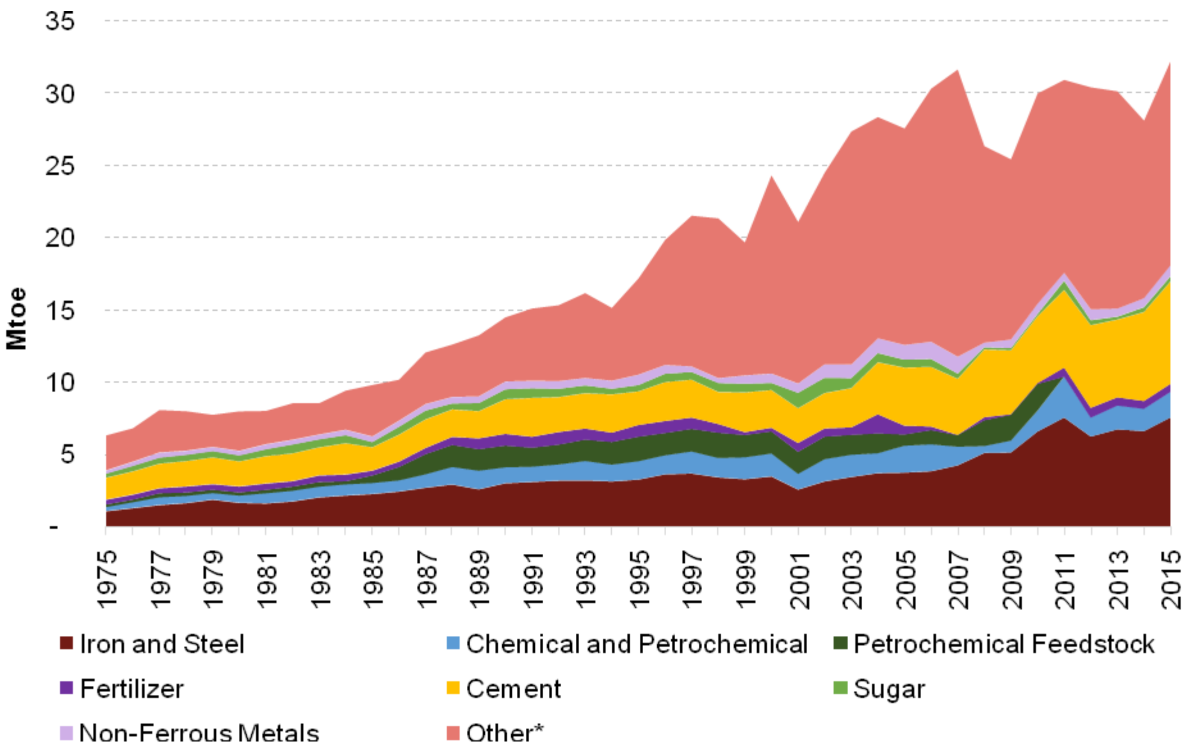

Figure 7. Industry Sub-Sector Energy Consumption Trend in 2015

Source: MENR, 2015. Other includes food and tobacco, textile and leather, paper-pulp and printing, ceramic, glass and glass products, motor vehicle industry, wood, mining, furniture industries.

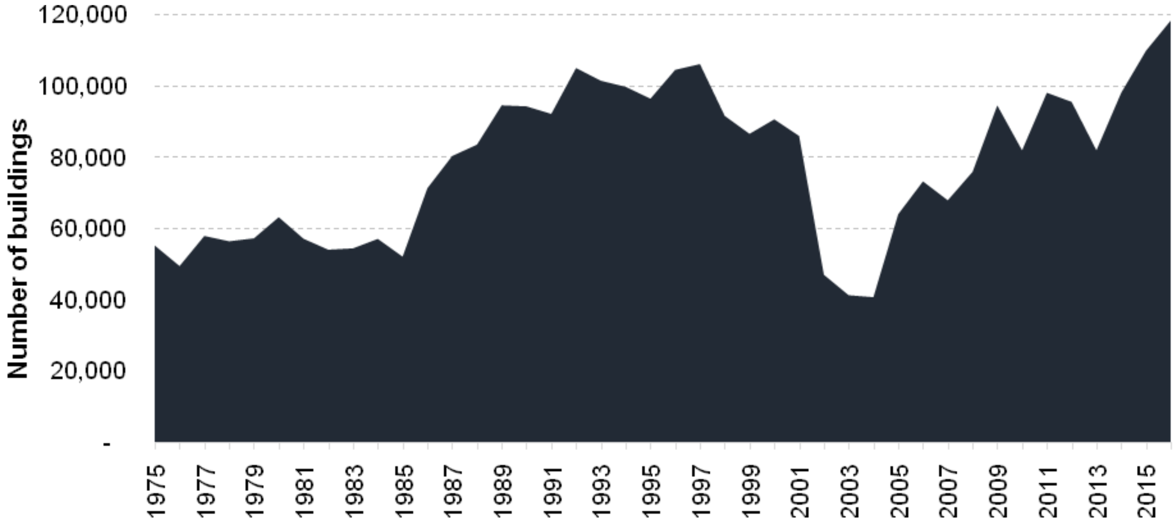

Figure 8. Number of Buildings Constructed in each Year (Data Source: TurkStat, 2016)

Energy Figures indicate that, in Turkey, power generation and industrial sector are responsible for more than half of the GHG emissions. The most energy consumer sector is industry, and the main reason is that construction-related industries, cement, iron and steel, dominate the energy demand. Therefore, eco-innovations in power generation and circularity in industrial sector could create more sustainable loops.

Turkey had a rapid urbanisation in metropolitan cities by illegitimate growth during the 1960s and 1970s (Kocabas, 2013, p. 83). Istanbul, Ankara, Izmir and Bursa, western metropolitan cities of Turkey got migration from rural parts of Anatolia (ibid) during this process. Single storey dwellings, which did not have urban services was built illegally (ibid). In 1965, single storey dwellings ownership was enacted; thus, a housing development was established and construction companies replaced one-storey dwellings with 4-5 storey concrete buildings (ibid). This trend caused significant cement consumption and low environmental standards (ibid). Buildings built after 2000 have energy efficiency standards as EU countries; however, nearly 75% of new buildings have not complied with building standards (ibid). Therefore, fundamental changes are needed.

Energy Efficiency Law (2007) forces certain sized buildings and industrial plants to audit their energy consumption since 2011 (IEA, 2016, p. 54). Energy management is necessary if:

- Industrial plant has more than 5 000 toe energy consumption per year,
- Service sector buildings which have more than 20 000 m² total built area,
- Public buildings which have more than 10 000 m² total built area or 250 toe energy consumption per year.

The government has a target to turn 25% of 2010 building stock into sustainable systems and having heat insulation and energy-efficient heating systems until 2023 (IEA, 2016, p. 56). Moreover, central heating and individual metering and control system are also mandatory since 2010 and 2012 respectively (ibid). Energy Efficiency Law and Energy Performance Certificate will help in order to achieve these targets; however, policies related to low-carbon buildings doesn't seem enough to cover all the scales in the built environment (Table 3).

Table 3. Summary of Policies Related to Low-Carbon Buildings

Policy	Impact	Affects through;
The Efficiency Improvement Project (EIP) The Voluntary Agreements Support Scheme Incentive schemes for industrial investments	Indirect	Reducing energy intensity during the production of construction material
Energy Efficiency Law	Direct	Monitoring certain size buildings in each sector
Energy Performance Certificate (EPC)	Direct	Increasing energy efficiency of the buildings and reducing energy consumption via insulation and efficient heating systems.

The construction sector plays a significant role in the economy of Turkey because of new housing, infrastructure investments and high earthquake risks (Arslan et al., 2012, p. 314). GDP from construction sector has reached 20% share in other sectors (Trading Economics, 2017). Despite the positive growth, construction and demolition activities generate a large amount of waste, with renovations causing 30-50% of overall construction wastes (Arslan et al., 2012). Moreover, 74% of construction materials which are renovated are dumped. Therefore, the construction industry needs to be more efficient in terms of material and resources. There are little research and practical applications of circular economy in the modern built environment at the product and component level in Turkey. Current research mainly focuses on recycling construction and demolition waste, there has not been any attention to the reuse of products. This study contributes to the current research by addressing the gap for low-carbon buildings in Turkey and establishing a framework for Circular Kayseri city model.

5.3 Analysis of Kayseri as a Circular City

Kayseri is a city located in the middle of Turkey, and more than 1,3 million people live in the city (TurkStat, 2016). The main economic sectors are services and industry with the share of 48.8% and 36.8% respectively; therefore, trade with other cities and imports & exports have a significant impact on the economy. The main manufacturing sectors are furniture, textile, and metal product, which accounts for two-thirds of the exported product economy and nearly whole imported product economy (Figure 9). On the other hand, 80,000 people and a quarter of total industrial companies work in the construction sector in Kayseri (CADA, 2013). In terms of construction materials, brick dominates the other materials with 38.3%; however, stone and hollow concrete brick have also high share with 30.9% and 25.4% respectively. Moreover, around Europe, Turkey has 53% of total pumice mineral reserves, the raw material of hollow concrete brick, and 25% of this stock exist in Kayseri (Table 4).

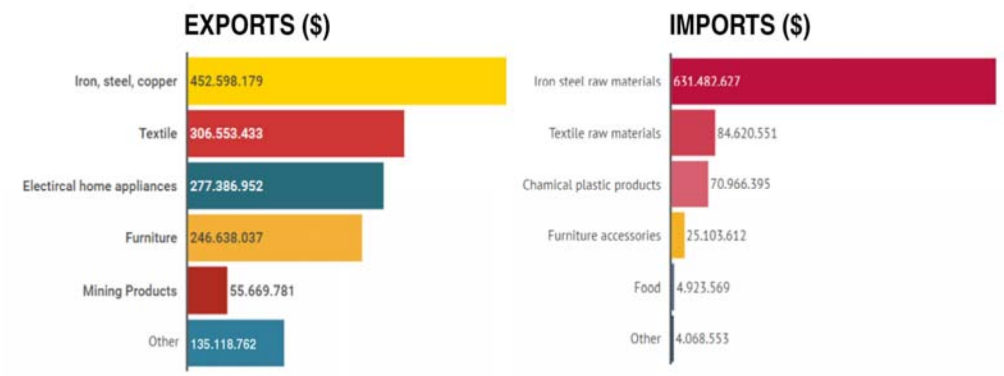

Figure 9. Import and Export Distribution by Product (Kayseri Chamber of Industry, 2017)

On the other hand, in terms of energy, Kayseri consumes 2,855 GWh electricity and 546 million m³ natural gas per year. More than half of the electricity has consumed by industrial sector. In terms of waste production 416,541 tonnes of solid waste has been collected and 62.6% of the total amount was the organic waste (TurkStat, 2016). There are several landfill sites, and even though recycling activities becoming popular landfilling is the common waste management system in Kayseri. These findings indicate that construction sector and built environment has a significant impact in Kayseri. The circular economy model could create a sustainable development in the industry; therefore, Circular Kayseri model has been adopted and framework has been established.

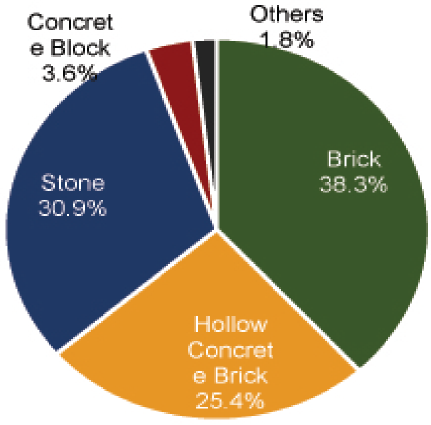

Figure 10. Construction Materials Used in Buildings in Kayseri (TurkStat, 2016)

Table 4. Construction Material Stock Extracted in Kayseri (CADA, 2013)

Name of Mine	Unit	Estimated Reserve	Place of use in the construction process
Pumice	tonnes	725,000,000	Pozzolan Cement, Hollow Concrete Block, Prefabricated Building Materials
Brick, Roof Tile	tonnes	18,000,000	Wall Materials, Roof Materials

Diatomite	tonnes	12,750,000	Lightweight Concrete Materials, Glass Products, Brick, Paint
Iron	tonnes	10,000,000	Structural Iron, Scaffolding, Railing, Steel Door, etc.
Sand, Aggregate	m^3	4,600,000	Cement, Plastering, Concrete
Gypsum	tonnes	1,500,000	Ceramic, Gypsum Plaster, Plaster Board, Sanitary Products

Several steps have been applied for Kayseri to define its future vision as a circular city.

The first step of the theoretical model is identifying circular indicators such as ecological impacts, economic values, value retention and so on Table 5 shows 11 sectors in Kayseri and their impacts on ecological and economic indicators based on Analytical Hierarchy Process (AHP) method. The AHP method initially proposed by Saaty (1980) is based on pairwise comparisons. A detailed description of the AHP can be found in Saaty (1990, 2008). AHP adopts a subjective assessment of relative importance converted into a set of weights, which structures the problem in a hierarchical way (Spataru et al., 2014). We then grouped the intensity of importance into the low, medium and high grade. Table 5 indicates how dominant one element is over another with respect to the criterion. Construction, metal goods, furniture and food and beverage industries have higher impacts in terms of economic interest. On the other hand, construction, metal goods and plastic industries have higher impacts in terms of environment.

Table 5. Evaluation of Economic and Ecological Impacts of Sectors in Kayseri

Indicators	Ecological Impact	Economic Interest
Construction Industry	High	High
Metal Goods Industry	High	High
Furniture & Home Textile Industry	Medium	High
Mining Industry	Medium	Medium
Chemical Industry	Medium	Medium
Food & Beverage Industry	Low	High
Plastic	High	Low
Furniture	Low	Medium
Electrical Home Appliances	Low	Medium
Agriculture Industry	Medium	Low
Tourism	Low	Low

For Circular Kayseri, construction chain has been selected because of its high impact on ecological and economic indicators and high material and energy demand in the industrial sector. Sub-indicators have been identified and detailed strategy have been analysed (Figure 11) in terms of four main concepts;

- Smart Design
- Deconstruction & Separation
- High-Value Recycling and Reuse
- Marketplace and Resource Bank

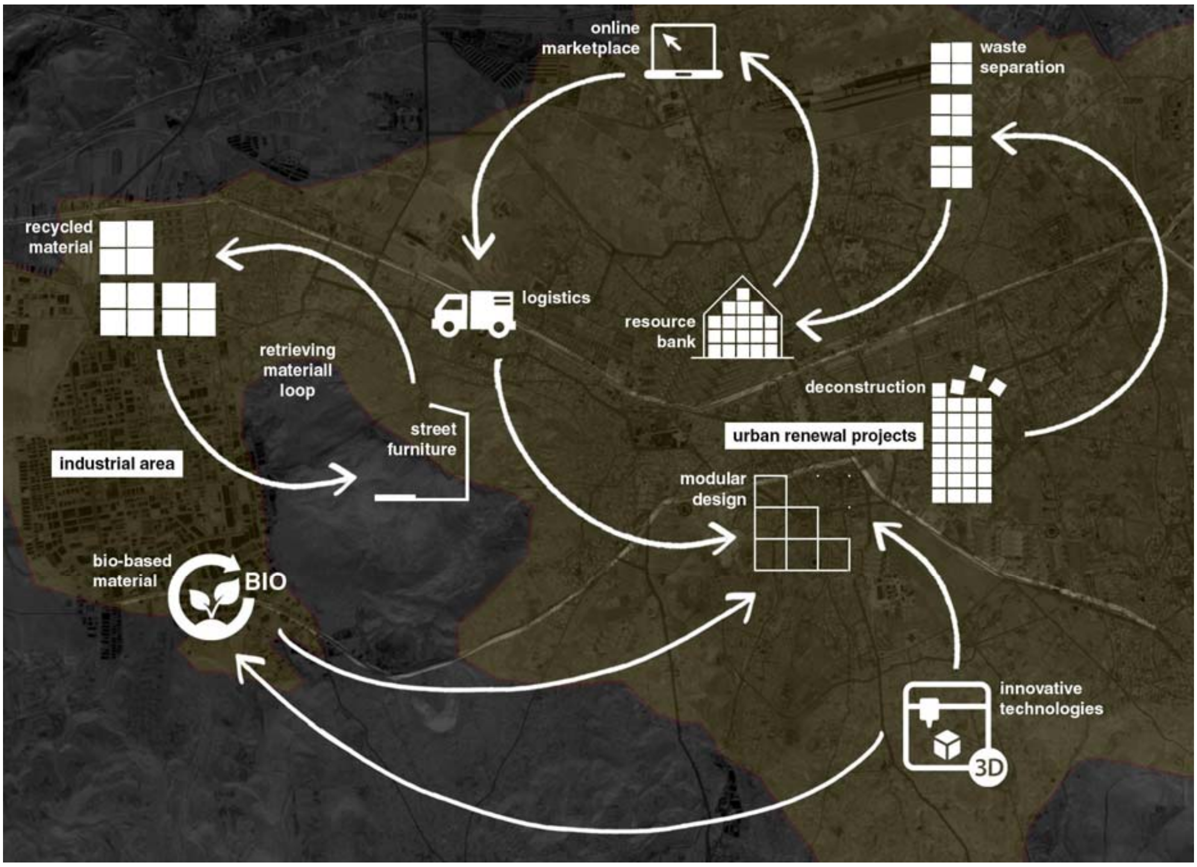

Figure 11. Visualisation of Circular Economy City Model for Kayseri

The four main concepts described in the theoretical model (Figure 3) have been applied for Kayseri, analysed and discussed in the following sections.

A. Smart Design

The traditional designing process creates spaces for specific purposes; however, in the real world, the purpose of the building may change in order to adapt to different work patterns (Circle Economy, 2016, p. 22). This situation creates renovation in the building and produces more waste. Reducing the waste through preventing actions that create the waste should be the main principle for the circular chain. Therefore, smart design principle has a significant impact on material consumption. This principle has been categorised into four main concepts.

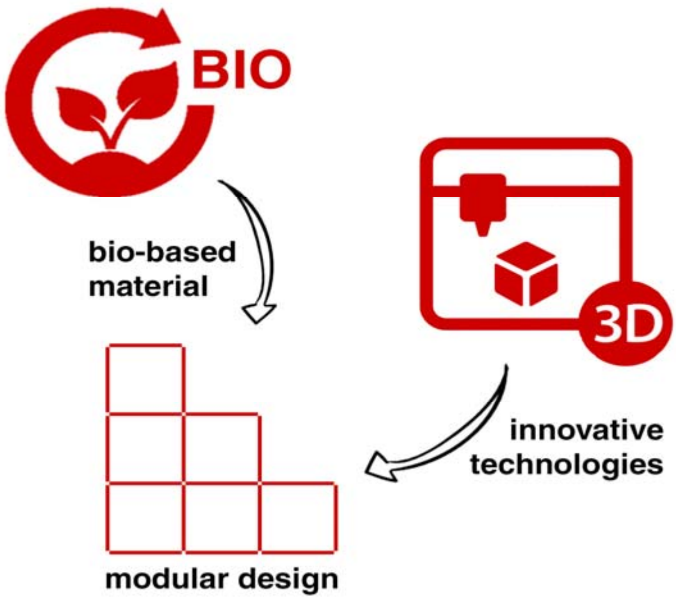

Figure 12. Proposed Smart Design Concept for Kayseri Circular City

Flexible design: Flexible design activity could create modular and flexible spaces that can be adapted to the new users easily (Circle Economy, 2016, p. 22). Residential users and companies often prefer flexible houses and offices because when their lifestyle and business environment has changed they can adjust to the differences. Local government and architectural design firms could collaborate to create a common sense of flexible and modular design principles.

Innovative technologies: Could create more efficient construction chains by reducing cost, time and material consumption (Circle Economy, 2016, p. 22). 3D printing is transforming the construction sector remarkably (EMF, 2015, p. 84). It has been shown in China in 2014, a Chinese company, WinSun, printed ten houses in 24 hours. Each house was about 195 m² and cost about €5,000. During the construction, on the other hand, 30-60% less material was used than traditional methods. As a construction material, a mixture of dry cement and construction waste was used.If a similar project is applied in Kayseri similar results could be provided. The main part of this section is adopting the technology; thus, research projects related to similar innovations could be supported in universities through Kayseri's local government. Therefore, construction companies can also benefit from these innovative solutions and started to use them.

Clean building material: New developments in construction materials have been helping to create more sustainable and ecological built environment (Circle Economy, 2016, p. 22). Biomass and agricultural waste, for instance, could be used to produce bio-based materials. Moreover, a pilot project in Amsterdam has been introduced in order to create building materials through capturing CO_2 emissions. Currently, Kayseri has several landfill areas for the waste management system, and organic waste is account for 63% of the total waste stream (DGEIAPI, 2013, p. 32). Agricultural activities and organic waste flow could be connected to material production sector; thus, organic components could be reused in new construction materials.

Experimental construction areas: Smart design is a multi-disciplinary concept which has different enablers from academia, industry and the private sector. Therefore, creating experimental construction areas which have more flexible building codes and regulations could help to examine practical applications in the construction area (Circle Economy, 2016, p. 22). Currently, Kayseri has several urban renewal projects. Sahabiye Urban Renewal Project, for instance, has four main stages. During the first stage, 63 new buildings (472 dwelling and 40 offices) will be constructed. These urban renewal areas can be used as an experimental area; therefore, practical applications could be investigated in these projects.

B. Deconstruction & Separation

Current practices often ignore the end-of-life phase while calculating the life cycle of a building; however, dismantling and separating the waste could help to save high-value materials (Circle Economy, 2016, p. 24). Smarter decommissioning and separation phases on a regional scale could achieve beneficial reuse targets.

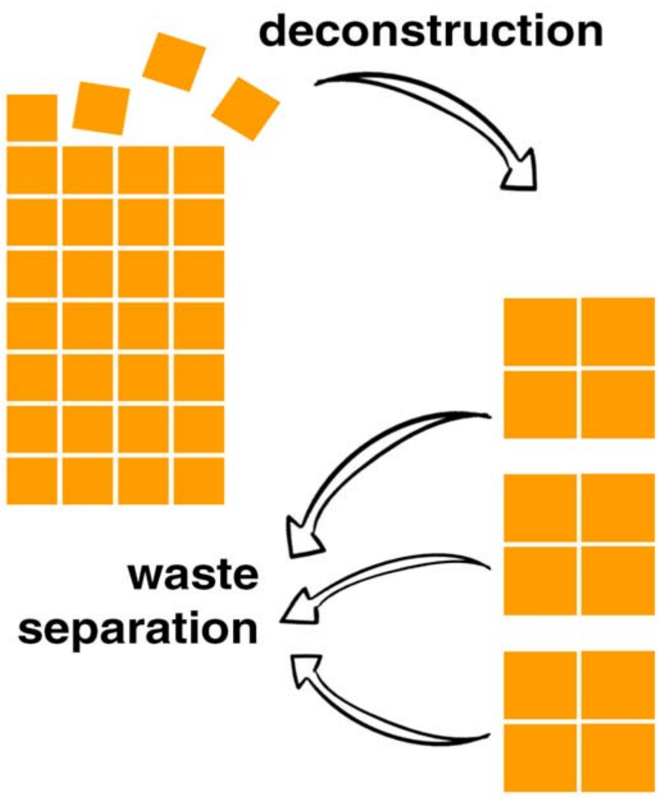

Figure 13. Proposed Dismantling and Separation Concept for Kayseri Circular City

Decommissioning: Circular construction chain includes cooperating partners from DBFMOD (Design, Build, Finance, Maintain, Operate and Demolish) phases (Circle Economy, 2016, p. 24). Demolishing phase creates an opportunity to save the material from being a waste. Moreover, selling these materials could repay the demolition costs. In Sahabiye renewal project, all existing buildings have started to demolish. New companies specialised in decommissioning and demolishing could be established, and waste material coming from this demolition could be separated through these demolition companies.

Waste separation: Separating the construction and demolition waste could prevent losing high-value materials (Circle Economy, 2016, p. 24). Smart waste management systems can create individual, central and regional separation systems which help to arrange waste construction materials. Similar to decommissioning companies, waste separation companies could be established, and used in order to process the waste and separate high-value materials.

C. High-Value Recycling and Reuse

Construction waste is one of the major factors which contribute to the total waste stream in cities (Circle Economy, 2016, p. 26). Therefore, high-value recycling could create better reuse options in construction chain. On the other hand, using existing building stock effectively can also contribute to high-value principle.

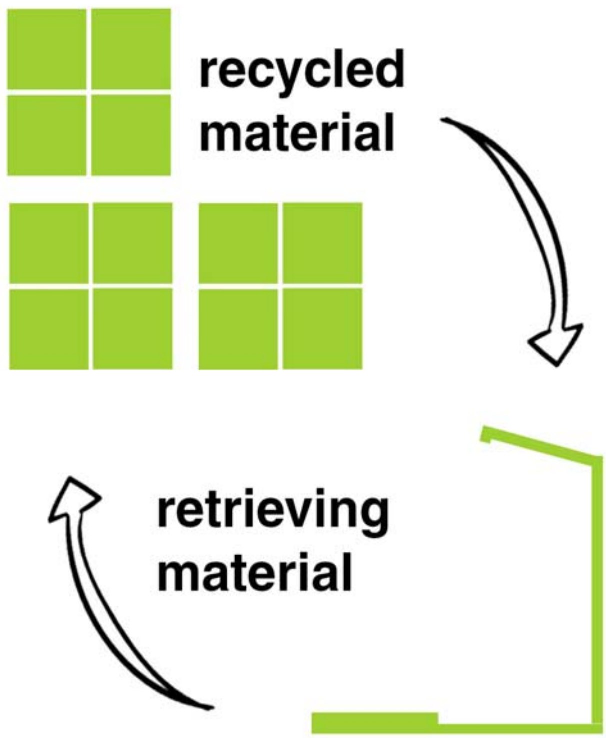

Figure 14. Proposed High-Value Recycling and Reuse Concept for Kayseri Circular City

Better reuse: While producing new construction material better reuse methods could be adopted. In Amsterdam, for instance, several companies produce brick from stone and ceramic waste (Circle Economy, 2016, p. 26). As Kayseri's building stock has mainly brick, stone and hollow concrete brick as a construction material, after the demolition, these materials become waste. If similar actions are applied in Kayseri these materials could be reused to produce new materials for new construction projects.

Retrieving materials from street furniture and paving materials: In Kayseri, renovation in street furniture and pavements is a frequent practice for years. During these renovations, using recycled waste material coming from existing pavements or street furniture can create a closed loop for public areas in terms of circular chain (Circle Economy, 2016, p. 26). A Dutch company, Struyk Verwo, uses old concrete pavements to produce 70% recycled new pavement materials (ibid). Similar practices could be adopted in Kayseri in order to recycle existing pavement material.

Repurposing existing buildings: Vacant and excessive buildings consume more energy and material than efficient ones (Circle Economy, 2016, p. 26). The average size of dwelling between 2012-2016 was 137 m^2 in Kayseri according to TurkStat (2016) data. In Europe, on the other hand, the average was only 96 m^2 (Eurostat, 2013). This number indicates a cultural difference in terms of living conditions; however, understanding the major problem for this issue could help to save energy in residential buildings. Qualitative research methods could be used to measure this problem and community's understanding. Then, efficient architectural design practices could be examined in Sahabiye urban renewal project.

D. Marketplace and Resource Bank

The built environment has great potential in terms of building material resource (Circle Economy, 2016, p. 26). Decommissioning processes could provide recovered materials to new construction projects. However, storing, marketing and transporting these materials is a complex business. Therefore, a resource bank, an online marketplace and logistics are needed.

Figure 15. Proposed Marketplace and Resource Bank Concept for Kayseri Circular City

Resource Bank: Construction waste needs to be stored temporarily on a vacant site in the city (Circle Economy, 2016, p. 28). Before the trade, the material can be identified and organised here. This place could be an alternative commodity bank for designers and architects. Vacant plots in Kayseri could be identified and examined for waste material storage before traded through the online marketplace.

Online marketplace: Supply and demand of building materials could be managed in an online marketplace; therefore, building passports,the quantity of materials and their specifications could be shared online to the public (Circle Economy, 2016, p. 28). In 2008, a British company, Enviromate has created an online trade system for construction companies which can exchange waste materials in the United Kingdom (Enviromate Products Corp., 2017). Similar online marketplace systems could be created to manage the trade of waste materials in Turkey.

Logistics for collection: Transferring the waste material from resource bank to the new location through advanced logistics and effective collection system could create cheaper and easier marketplace for users (Circle Economy, 2016, p. 28). In Kayseri, links with regional marketplaces could be connected through existing railway system; therefore, the centre of logistics can be created nearby the train station. Existing logistic companies could also contribute to the system through reverse logistics.

These four steps are the pillars of circular construction chain in Kayseri. However, each step has also barriers in terms of technology, market, policy and culture; therefore, understanding these barriers could create a more applicable model. While measuring these barriers, literature review (Circle Economy, Van Eijk and *Acceleratio*) has been used. Table 6 illustrate that even though technology does not have a high-value barrier, developments of technological innovations in design and recycling process could be a medium value barrier. Establishing the marketplace and resource bank could be a high-value barrier. On the other hand, regulating the policies could be challenging in all steps except the last one because of the existing regulations. The most challenging barrier could be culture because the new system needs collaboration between all actors, and traditional thinking could be a high-value barrier. For further research, interviews and surveys from the industry and the community could also be used.

Table 6. Barriers of Circular Construction Chain in Kayseri

Barriers	**Technology**	**Market**	**Policies**	**Culture**
Smart Design	Medium	Low	Medium	High
Deconstruction & Separation	Low	Low	High	Medium
High-Value Recycling and Reuse	Medium	Low	Medium	High
Marketplace and Resource Bank	Low	High	Low	Low

Using the approach defined in this research will help to implement a circular economy framework in cities. The implementation of the theoretical model requires cooperation between policies, funding and teamwork and awareness (Figure 16).

Figure 16. Three Tools Enabling Circular Kayseri City Model

5. Discussions and Conclusion

Most research focuses on environmental and economic aspects of the circular economy; yet, few of them address the social impacts of the circular economy (Geissdoerfer et al., 2017, p. 10). However, the more comprehensive view could help to create a system which based on all dimensions of the sustainability. Circular economy represents a productivity in resource, waste and energy streams. This principle could be achieved through a durable system which considers all the cooperating partners from built environment (design, build, finance, maintain, operate and demolish).

Accessing the data in city scale was the major limitation of the study. It is mainly because the topic is quite new in Turkey and databases do not have detailed collection system. Integrity between the databases does not seem consistent. Therefore, further research on the circular economy and sustainability projects need to be done; thus, awareness and benefits could be covered. On the other hand, during the first step of the model which is identifying the indicators more qualitative research (interviews and surveys) needs to be done in order to understand the impacts of the model.

This study has adopted a circular economy approach to cities with a focus on Kayseri as a case study. Key conclusions have been drawing from the analysis:

Architects and designers are the starting point of circular chains in the built environment because their decisions in the designing process can affect all the material cycle. Therefore, understanding the circular economy concept is crucial for them as they could affect the decisions through communication between the client and the contractor.

Adopting technologies for innovative solutions in material production and construction process is a fundamental step because these projects could create efficiency in each cycle of the material stream. Moreover, clean product activities could also help to reduce CO_2 emissions.

Technological developments need to be tested; therefore, flexible experimental areas could be created. These places could also help to raise awareness of the community and other private investors.

As the circular city model proposed, companies specialised in decommissioning and waste separation need to be established in order to create a demolition waste management system.

Cooperation between sectors and chains is crucial because idling of the system could be ensured by collaboration.

The last but not the least part of the model is policies because the integrity of the system could only be created by radical policies. The viability of the system depends on the success of the regulations; therefore, adopting policies which have already succeeded could be a vital point for the sustainability.

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