Lessons from Net Positive Energy to be applied in Net Positive Material flows

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ABSTRACT: The emerging notion of regenerative design promotes a co-evolutionary, partnered relationship between humans and natural systems. Implicit in regenerative design the act of building over time buildings can give more than they require – that is, they are net positive. In the recent years the notion of net positive has garnered interest in the context of energy and water flows. However, due to the complexity and longer timeframe of material flows, the notion of net positive in relation to materials use has not yet been explored or developed. The work presented in this paper explores the lessons that can be gained from the current definitions and characteristics of net zero and net energy positive buildings to possibly form a basis for understanding net positive materials flows.

1. INTRODUCTION

The extraction, manufacture, and transportation of building materials have considerable environmental, economic and social impacts. In general, green buildings have the objective of doing less harm in their construction and operation by reducing local and global resource depletion and environmental degradation (McDonough & Braungart, 2002; Reed, 2007). In the context of this paper, green buildings strive to reduce the negative environmental effects of materials use by using more local materials, recycled and recyclable materials instead of new materials, or by minimizing the amount of materials or eliminating certain materials completely. By contrast, as presented by Cole (2012), the emerging notion of regenerative design and development 'promotes a co-evolutionary, partnered relationship between humans and natural systems and, in doing so, build rather than diminish social and natural capital' (p.40). A key idea in regenerative design is the potential of some buildings to give more than they require – that is, they can be net positive. Although the notion of net-positive has been acknowledged in the context of energy and water flows, due to the greater complexity and longer timeframe of material flows associated with buildings, it has been given little attention in relation to materials use.

In the context of energy flows, the design of net zero/positive-energy buildings as necessary performance aspirations is now widely considered and, indeed, are increasingly embedded in national energy policies as many countries have declared that all new buildings must conform to net zero-energy and/or carbon neutral emission standards by a certain date (Kolokotsa, Rovas, Kosmatopoulos, & Kalaitzakis, 2011; Dyrbøl, Thomsen, Albæk, & Danfoss, 2010). This paper raises the possibility that the notion of net zero and net-positive may equally be applied to materials flows. In order to develop an understanding of "net-positive material flows" as it relates to buildings, a number of specific questions emerge related to the baseline against which net positive is defined, the most appropriate timeframes, and relevant boundaries to frame a definition. The study presented in this paper explores the potential lessons that can be drawn from the key features and literature that has attempted to provide a definition of Net Zero Energy and Net Positive Energy buildings and its applicability for developing the concept of Net Positive Material flows. Torcellini et al., (2006), Kolokotsa et al., (2011) and Marszal et al., (2011) and others have presented and critiqued the currently accepted criteria associated with the definition and technical aspects of zero/positive energy buildings. These studies have formed the main reference sources of this paper as the basis for understanding the major features of the notion of net positive energy buildings and their appplicability to materials use.

2. NET ZERO AND NET POSITIVE: ENERGY

2.1 *Definitions*

Kolokotsa *et al.,* (2011) describe a net zero energy building as one in which the 'energy demand for heating and electrical power is reduced to an extent that it can be met on an annual basis from a renewable-energy supply' (p.3067). Torcellini *et al*., (2006) raise a number of issues underpinning the current definition of net-zero energy, such as:

- Whether the renewable-energy supply sources are located on the building, on the site or can be purchased off-site.
- The grid is used to supply electrical power when there is no renewable power available, and the building will export power back to the grid when it has excess power generation.
- Distinctions are necessary between whether the evaluation is based on primary energy, site energy, carbon emissions, or cost.
- Distinctions are necessary between all-electric buildings and those with a combination of electricity and natural gas.

With the notion of a net-positive building as Kolokotsa *et al.,* (2011) state, 'the 'two-way' flow should result in a net-positive export of power from the building to the grid' or to neighboring buildings. However, since different types of energy resources such as fossil fuels, solar, and wind have different environmental impacts, Kilkis, (2007) emphasizes that in order to understand the real environmental impacts of buildings it is important to consider the quality of energy – i.e., exergy[1] – in addition to its quantity. Therefore, she proposes a new definition for the term NZEB – *'*a net zero exergy building that has a total annual sum of zero exergy transfer across the building-district boundary in a district energy system, during all electric and any other transfer that is taking place in a certain period of time' (Kilkis, 2007). Of significance to this paper, the definitions of both net zero energy and net positive energy buildings are currently premised primarily on environmental (energy) and economic (energy costs) criteria.

2.2 *Declaring the Baseline*

The baseline condition against which net-positive is assessed can be simply defined as the state in which generated and consumed energy are equal in a building in a yearly basis - that a net zero energy building. Therefore, a NPEB could conceivably be a building wherein the supplied renewable energy exceeds the required amount of energy, but little had been done to reduce energy demand. However, as the ultimate goal of NZE/PEB is to reduce energy, it is important to apply energy efficiency strategies in such buildings in order to reduce energy demand before supplying renewable energy (Iqbal, 2004; Torcellini et al., 2006; Marszal *et al.,* 2011). In this sense, NZE/PEB design concept can be considered, as Kolokotsa *et al.,* (2011, p.3068) stated, *'*a progression from passive design'.

2.3 *Declaring the Time-frame*

As the energy demands of buildings vary through time to a great extent, different time-frames have been identified for defining/measuring the energy production/consumption balance of buildings. It can differ from monthly, yearly, operating time of the building, or whole life cycle of the building. Most of the definitions for NZEB consider energy exchange of buildings in a yearly basis (Marszal, *et al.,* 2011) since this offers several benefits:

- Consistency with most of the building energy simulation programs (Marszal, *et al.,* 2011);
- Reducing the complexity and uncertainty of dealing with energy consumption during production, construction, and deconstruction stages.
- Addressing the seasonal changes in the weather and energy demands.

However, a yearly balance fails to consider unexpected weather changes from year to year, e.g., severe or mild winters. Moreover, as operational energy is reduced through energy efficiency strategies, the initial embodied and decommissioning energy become more significant (Sartori, Napolitano, Marszal, Pless, Torcellini, & Voss, 2010). Hence, as Hernandez & Kenny, (2010) suggest, despite all the complexities, complete life cycle of a building is the most accurate and comprehensive time-frame for assessing the balance between energy consumption and production in a building.

2.4 *Declaring the Boundary*

Physical boundaries can be defined for both supply and excess of renewable energies. In terms of renewable energy supply, sources can be located on the building site such as solar panels or they can be transported to the site e.g. biomass (Marszal, *et al.,* 2011). Torcellini, *et al.,* (2006) provided a general categorization and also a ranking for preferred renewable energy sources which is represented in the Figure 1. in which the lightest is the most favorable type of energy supply.

In terms of the excess of renewable energy, for the off-grid Zero Energy Buildings – those not connected to the grid – it can be stored in batteries for future consumption of the building itself. For the on-grid Zero Energy Buildings – those that have connection with the grid –it can be sold to the grid (Marszal *et al.,* 2011; Pless & Torcellini, 2010) or it can also be sold to the neighbor buildings. Considering the interaction of neighborhoods in terms of transferring the excess energy opens up a new forms of partnerships and challenges to current notions of ownership. As off-grid ZEB requires large amount of storage and also they are incapable of interaction with the community in terms of trading the energy, they are less favored in current practice (Torcellini, Pless & Crawley, 2006).

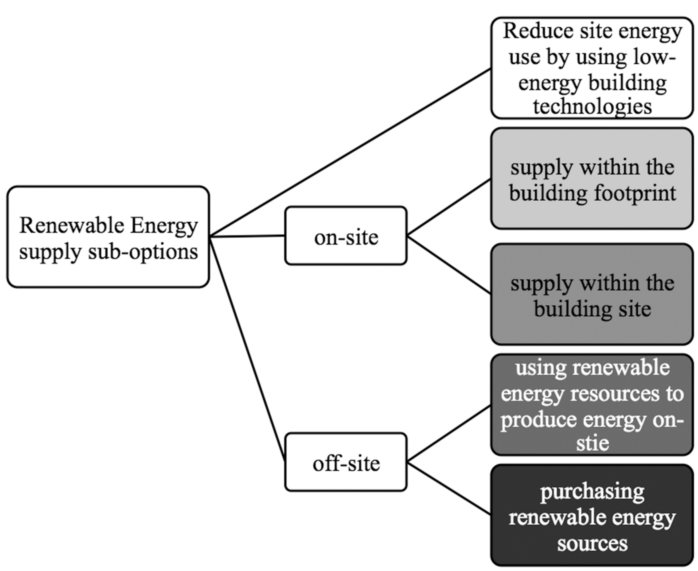

Figure 1. NZ/PEB Renewable Energy Supply Option Hierarchy . Based on Torcellini, (2006)

2.5 *Uncertainties*

Kolokotsa, *et al.,* (2011) provided a definition for the Estimated Net Energy Produced (ENEP) as an indicator for NZ/PEB studies. ENEP, they suggest is 'the energy available from renewable sources over a period of time after subtraction of the energy required for the building operation over the same period.' (p.3068). They further point out that the actual figures for this indicator can vary widely from the estimated computation in the design phase. They relate these uncertainties and variations to a number of factors: unpredictable user-behavior, changing weather conditions, generation–consumption matching, operation of active and passive climate-control systems; and, atypical availability of energy on a "weather-basis" rather than a "need-basis" (p.3068). Kolokotsa, *et al.,* (2011) conclude that neglecting of these variables in the assessment of ENEP asserts the 'static and simplified' nature of this indicator, which result in catastrophic differences between estimated and actual building energy performance. It accentuates the requirement for a more adaptable and dynamic view toward NZ/PEB.

3. NET POSITIVE: MATERIALS

This section explores the parallels between Net Positive Material Flow (NPMF) and the characteristics of Net Zero Energy/Net Positive Energy identified above.

3.1 *A Quantitative Definition of NPMF*

Similar to the definition of net positive energy buildings, a metric is required for defining NPMF. By contrast, in the context of construction materials, since the "production" of materials throughout the life of a building is not an option, the notion of net-positive material flow cannot be defined as producing more material than used in a building through its lifetime.

One possible quantitative definition for NPMF could relate to the number of times which a material is recovered and reused, with the material flow considered to be net zero if materials are recovered just one time. Here, by using a material more than once the necessity of reproducing the same material is eliminated the same number of times as it is recovered. This would lead to a net positive material flow. The metrics for assessing the amount of recovered materials can be based on mass, volume, cost, etc. However, this definition remains problematic for a number of reasons:

- As the time frame is much larger than energy flows, a considerable uncertainty exists about how the future will unfold. Thormark, (2001) and Saghafi and Hosseini Teshnizi, (2011) emphasize that despite an anticipated greater future need for the recovery of materials, whether or not a material or component will actually be recycled depends on many factors such as: the time required for its recovery, the risk of working in the area for building disassembly, variety of possible uses of the material, changes in the construction techniques in future, etc. The uncertainty increases when it comes to the understanding the potential number of times that a building material or component will be recovered in a relatively distant future.
- The quality of material recovery should be considered in any definition. For instance, some materials can be reused without requiring too much additional processing, while some others can only be used to produce recycled content materials.
- There are also different qualities of reusing materials, i.e., some materials can be reused in the same function and with the same quality, while the quality of others will decrease in their lifetime and thereby reducing their potential to be used in the same function.
- The benefit of considering cost as the metric for assessment is that the quality of recovered material can be reflected in its economic value. Nonetheless, similar to NPEBs, fluctuations in material market affect the credibility of cost as a measure.

3.2 *A Definition of NPMF Based on Regenerative Design*

The definition for NPMF could possibly be derived from one of the core ideas of regenerative design: the notion that buildings can be designed to provide positive impacts rather than simply reducing negative impacts. Here, NPMF can be defined based on increasing or shifting of value associated with material flows through their usage in the built environment. Currently, despite many technical and economic improvements in the use of reclaimed materials, the overall value of building materials[2] decreases at the end of a building lifetime. Hence, few building materials are considered sufficiently valuable to be reused or recycled at the end of buildings' lifetime. This reflects an imbalance between different types of value attributed to material flows and hence the primary purpose of research on NPMF introduced in this paper is to recognize the various values ascribed to materials, the interconnections between them and the possibility of increasing the overall value during materials' life-time. Understanding and assessing the interaction between quantitative values (e.g., environmental impacts) and qualitative values (e.g. social/cultural value for new material) is a major consideration within this work. A key notion is to understand how the current linear use of materials can be turned into a closed loop as a result of the added overall value. This definition addresses the problems of the quantitative definition in dealing with the number of times that materials are recovered and also quality assessment of material recovery.

3.3 *What are Types of Value ascribed to NPMF?*

Published literature on building materials selection tools acknowledges that the criteria that affect materials selection can be grouped under various categories covering both technical and non-technical criteria. However, current building material assessment tools mostly concentrate on the technical performance criteria. Although materials should be considered in terms of fulfilling physical, economic, socio-cultural, and environmental requirements, the physical, environmental and economic requirements are typically given greater emphasis in current material selection tools. Many qualitative factors such as aesthetic or cultural values are ignored in these tools (Akadiri & Olomolaiye, 2012). Furthermore, current studies and tools do not consider the interrelation between different criteria primarily because of the discipline specific nature of the research that generative the performance criteria.

The current literature on the environmental assessment tools provides some understanding of the values related to material flows in the building industry. The UK's Building Research Establishment Environmental Assessment Method (BREEAM), Japan's Comprehensive Assessment System for Building Environmental Efficiency (CASBEE), and the US Leadership in Energy and Environmental Design (LEED) all emphasize the need reduce the environmental impact of materials use by encouraging the use of local materials and also encourage the use of recyclable, recycled content, rapidly renewable, and low-emitting contaminant materials (Castro-Lacouture, Sefair, Flórez, & Medaglia, 2009). By contrast, the South African Sustainable Building Assessment Tool (SBAT) highlights the importance of social aspects in sustainable building assessments (Gibberd, 2005). (See Table 1)

Over the past few years some specific material assessment tools are developed to assist design teams in choosing materials that meet the specific requirements of building assessment tool (Ogunkah & Yang, 2012). Life Cycle Assessment (LCA) is the most comprehensive method for evaluating the environmental (E-LCA), economic (LCC), and recently social impacts (S-LCA) of materials and products through their life cycle. Most of the building assessment tools are more or less based on LCA. Table 2 illustrates the focus area of some building and material assessment tools.

Table 1 Literature Review Domains

	Literature area							
	Green Building Assessment Systems				Material Assessment Tools			Regenerative Design
Values	LEED	CASBEE	SBAT	BREEAM	LCA	LCC	S-LCA	
Socio-cultural			●				●	●
Economic	○	○	●	○		●		●
Environmental	●	●	●	●	●	●		●
Physical	○	○	○	○		○		○
Scale								
Component	◐	◐	◐	◐	●	●	●	○
Building	●	●	●	●			◐	◐
Neighborhood	◐	◐	◐	◐				●

The inventory of environmental impacts that are associated with material consumption is well developed in LCA tools and typically contain criteria such as global warming, ozone depletion, eutrophication, and acidification, waste generation, etc. (Ramesh, Prakash, & Shukla, 2010). The costs associated with a material usage in its whole life-time are studied in LCC analysis tools. The physical value of a materials relate to the functional/performance requirements such as durability, weathering resistance, strength, etc., and have a primary impact on a design team's decision about material choice.

Socio-cultural value can be considered in two aspects:

1. Those that are attributed to the surrounding environment and can be improved by using a material, such as employment, human health, and equity;
2. Those that are attributed to materials and affect people's preference for choosing materials, e.g., aesthetic values, valuing new rather than old materials, etc.

Although this latter aspect has profound affects regarding the success of using reclaimed materials, it has been less studied in the existing literature. Arkes and Hutzel (1997) discuss a psychological paradox between people's typical dislike of wastefulness and yet have preference of new items. In their paper, they juxtapose these two inherent tendencies and recommend that when the natural features of a product is cued, people choose to preserve rather than replace. It is due to a common perception about limitation of natural resource supply.

The different values assume different importance or weight in different design contexts such as: building geographical location, building function (e.g., residential, commercial, and academic); function of materials in buildings (e.g., structure, finishing, etc.); visibility of materials in the building – materials which are visible in building are aesthetically more important in comparison to hidden materials; and stakeholders point of view – different stakeholders have different priorities in their decisions (See Table 2). A balance between the often competing values in the initial choice of a material is typically reached from having input from different stakeholders. Such decisions invariably become more complex when considering the potential impact of different values on each other and also their change through time.

Table 2 Impact of Variables on the Importance of Different Values

Variables	Building Function				Material Function			Material Visibility		Stakeholders		
	Single Family Residential	Multi-unit Residential	Commercial	Academic	Structure	Outdoor Finishing	Indoor Finishing	Visible	Hidden	Investor	Design Team	Resident
Values												
Socio-cultural	●	●	●	○	○	●	●	●		◐	◐	●
Economic	●	●	●	●	●	●	●	●	●	●		◐
Environmental	○	◐	◐	◐	◐	◐	◐	●	◐	◐	◐	◐

	Single Family Residential	Multi-unit Residential	Commercial	Academic	Structure	Outdoor Finishing	Indoor Finishing	Visible	Hidden	Investor	Design Team	Resident
Values												
Socio-cultural	●	●	●	○	○	●	●	●		◐	◐	●
Economic	●	●	●	●	●	●	●	●	●	●		◐
Environmental	○	◐	◐	◐	◐	◐	◐	●	◐	◐	◐	◐

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inition becomes explicit when quality of recovery, e.g., reusing in the same function, reusing in different function, recycling, etc., recovery percentage, and also the frequency of recovery are considered in comparison to the baseline condition.

Another alternative for baseline condition can be developed for the regenerative definition of NPMF, which is based on value assessment. A key premise of the work presented in this paper is that reclaimed materials should be chosen over new materials, if so, one possibility is that the base line for describing NPMF could be new materials. This baseline conveys that if the overall values – physical, ecological, socio-cultural and economic – of reclaimed materials reaches or exceeds new materials they will be preferred in the construction industry. The latter definition highlights the importance of the quality of resource recovery. Reclaimed materials can be divided into two major categories: recycled content materials and reused materials. As such, the different values that are discussed in Section 2.1 should be compared between new, recycled, and reused materials. A recycled content material might have higher physical and economic value, but lower ecological and economic value compared to a reused alternative. The percentage of recycled content in recycled materials should be considered in this analysis as it affects the values, e.g., the physical value of a material might decrease when its recycled content percentage is increased.

3.5 *Declaring the Timeframe*

In the material flows, due to its longer timeframe, an annual balance cannot be achieved. Hence, considering at least one building lifetime seems to be necessary both in quantitative and regenerative definition of NPMF. In quantitative definition, net zero can be achieved after finishing the first building's lifetime. However, as discussed before, achieving quantitative NPMF is highly unpredictable as it deals complex factors in a long timeframe.

Regenerative NPMF, on the other hand, deals with fluctuation of different values through material flows over time. These values may either remain stable, increase/decrease or shift. Socio-cultural values can shift based on the changing human mindset and society's collective priorities. These changes, many of which are unpredictable, result in an uncertainty about the future. Direct and indirect socio-cultural, ecological, economic, and physical values and their change in a declared/anticipated timeframe should be considered within the regenerative definition of NPMF. The aim of this research on NPMF is to identify the critical values which have the potential to be increased/shifted in order to increase the potential use reclaimed material.

3.6 *Declaring the Boundary*

Although individual materials or components can be studied in order to define NPMF, the definition will be considerably different if materials are considered within a larger system, e.g., building, neighborhood, city, or watershed. Considering materials within the scale of a neighborhood opens up the discussion of the possibility of developing local economies and markets for reclaimed materials. An established local market for reclaimed materials facilitates the access of the design team to reclaimed materials with expected quality and quantity. Here it becomes necessary to clarify who are the beneficiaries of improving local markets of reclaimed materials. In other words, from which stakeholders' point of view are local reclaimed materials considered to be valuable?

3.7 *Dealing with Uncertainty*

Owing to the large timeframe of building material flows, uncertainty is major issue in development of the concept of NPMF. Despite the recycling potential of a material, it is not clear whether it will be reclaimed at the end of buildings lifetime or how many times it will be recovered in its lifetime or how long it will remain in the materials cycle. Recovery of building material at the end of a building lifetime may be affected by budget, time, having a place for storage, demand for reclaimed material at the time of deconstruction, risks that are associated with the deconstruction process, and etc. On the other hand, whether reclaimed materials are considered as a major resource for new construction will be affected by presence of reliable reclaimed material with the desired quality and quantity, access to the database of reclaimed materials, relative cost of new and reclaimed materials, users' willingness and trust for using reclaimed materials, and etc.

The complex systems thinking embedded in notion of regenerative design highlights the idea that change and uncertainty are the only certainty we have. As such, it is clearly necessary to make this much more explicit in making strategic decisions and the tools deployed to assess their success. The future frameworks and assessment tools would, by necessity, have to accept uncertainty and therefore move toward promoting and assessing resilience and adaptive capacity of a system and its potential contribution to maintain and ideally improve the social, ecological and economic health (Du Plessis & Cole, 2011).

4. CONCLUSION

Although the idea of being net positive – which is a key notion in regenerative design – has been acknowledged in the context of energy and water flows, it has been given little attention in relation to materials use, mainly due to the complexity and longer timeframe of material flows associated with buildings. This paper suggested a new approach toward construction materials that is an effort for having positive impacts rather than reducing negative impacts. To investigate the possibility and main obstacles of applying this idea to building material flows, major aspects of Net Positive Energy Buildings (NPEB) are explored in the paper, in order to find out the lessons that can be learnt from them in developing the concept of Net Positive Material Flows (NPMF) (See Table 3).

Table 3 Comparison of Key Issues in Net-Zero and Net-Positive Definitions

	Net-Zero			**Net-Positive**		
	Energy	Material		Energy	Material	
		Quant*	Regen**		Quant*	Regen**
Metrics	- Primary Energy ●◆ - Site Energy ● - CO_2 Emissions ● - Cost ▲ - Exergy ●◆	Number of Recovery Times	**Values:** - Socio-cultural - Economic - Environmental - Physical ■▲●◆	*The same as NZ*	*The same as NZ*	
Baseline	Consumption=Production Consumption Reduction	Reused Once in the same Function	Value of New = Value of Reclaimed	Consumption ^ Production	Reused more than Once in the same Function	Value of New ^ Value of Reclaimed
Time-frame	- Annual - Building Operating Time - Whole Life Cycle	One life Cycle	One life Cycle	*The same as NZ*	More than One life Cycle	At least One life Cycle
Boundary	**Demand:** - Building - Site - Off-site - Grid **Excess:** - Grid - Storage	- Materials - Building - Neighborhood - City -Watershed - Country - World	*The same as Quant*	**Demand:** - Building - Site - Off-site - Grid - Neighborhood **Excess:** - Grid - Storage - Neighborhood	**Demand:** - Neighborhood - Local Sources **Excess:** - Neighborhood - Local Sources	*The same as Quant*

Focus Area: ■ Social ▲ Economic ● Environmental ◆ Physical Quality
* Quantitative Definition
** Regenerative Definition

Currently there is an existing gap between the awareness of benefits of using reclaimed materials and their use, especially for reusing building materials. An explanation for this issue can be the failure of current studies to incorporate a holistic view toward material flows. Despite a current awareness regarding the wide range of factors affecting building material selection, the majority of green material assessment tools still take into consideration only a limited range of factors (Ogunkah & Yang, 2012). These factors are mainly quantifiable technical, economic, and environmental factors. Most green building material assessment tools are, as Ogunkah & Yang (2012) suggest yet to 'incorporate social or cultural criteria directly into the decision making process, but instead incorporate them indirectly into technical or economic decision making criteria. (p.6) As a result of analyzing current practices in defining NPEB and comparing it with NPMF following major questions arise regarding NPMF, which require further investigation:

- How net-positive material flows can be defined? What is the appropriate metric for assessing NPMF?
- What are the values that can be changed through material flows? Is it possible to increase these values in material flows? Is it possible to shift social and cultural values, toward valuing reclaimed material more than new materials? How can the interrelation between social,

economic, environmental, and physical values be considered in assessing the overall value of materials?

- How can we go beyond the building boundaries and consider a material's value in a larger system rather than in an individual building?
- What is an appropriate timeframe for NPMF framework?
- What are the strategies for dealing with uncertainty about the future?

These questions form the basis of the primary ongoing research work introduced in this paper.

ENDNOTES

1. The concept of exergy quantifies the potential of an energy source to be dispersed. Exergy can therefore also be described as the "valuable part of energy" (Thesseling & Schlueter, 2009). After the system and surroundings reach equilibrium, the exergy is zero.
2. The overall value of materials is defined as the overall interactions between different values which are socio-cultural, economic, ecologic and physical values.

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