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New or Renew: Constructing Tomorrow with Kit of Parts

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Abstract In this paper, we would like to share our ongoing research on global population and demographic shifts and the corresponding need for diverse responses. As population growth varies worldwide, the pressing issue is the current global housing shortage. The USA alone lacks 4 million homes, underlining the urgency for new construction and renewal of existing. Our focus is primarily on new building processes, which must also incorporate elements of renewal for future sustainability. Our research addresses several key questions: How will roles for construction professionals change? What should be the primary goal of the design process? What types of technologies are currently available, and which aspects of the process can be enhanced with AI? A significant part of our study is exploring sustainable building methods that reduce embodied carbon and increase speed of construction. Our goal is to extend the transition from smart homes to cities, analyzing the evolution towards smart communities and cities. A critical aspect of our research is the 'kit of parts concept, involving prefabrication and modular construction. This approach is essential for both rebuilding and new projects, potentially lowering costs in manufacturing and design for long term. Lastly, we present a detailed comparison of the construction industry with manufacturing.

Keywords Global population, Housing shortage, Sustainable building methods, Modular construction, Artificial intelligence (AI), Advanced digital delivery, Prefabrication, Building information modelling (BIM), Process management.

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1. Examining Global Population Dynamics and Their Impact on Housing Shortages

Throughout most of human history, the world's population was significantly smaller than it is today. In the last few centuries, the number of human beings has undergone an extraordinary transformation. The world population was less than one billion in 1800. Today, however, the number of us has risen to over 8 billion (see Figure 1).

Rapid population growth in Asia, with Africa beginning to follow, is illustrated in Figure 1. This is an important milestone as demographers predict that global population growth will peak by the end of the century. Efforts in the areas of resource management, education, health care and infrastructure are needed to ensure a sustainable approach to population growth. It is essential to understand the social, economic, and environmental impacts in order to formulate policies for the long term. The construction industry will undoubtedly need to adapt as the world's population is expected to reach 10 billion by 2100.

Meanwhile, the decline in fertility rates that began in the 1800s is expected to continue through 2100 (Figure3), and improvements in health care and reductions in infant mortality will continue to reshape demographics. Analysis shows that population growth has consistently increased across all demographics from the 1950s to 2023, with a potential incline in the number of elderly individuals ahead. As seen in Figure 4, this trend may lead to a decline of working-age individuals towards the end of the century.

This research emphasizes the significance of demographic trends in shaping building and infrastructure planning, including senior living, towns, and other infras-

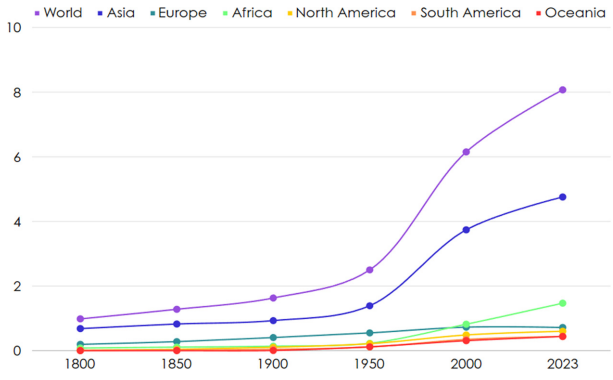


Figure 1. Global population: 1800-2023 (Figures in billion).

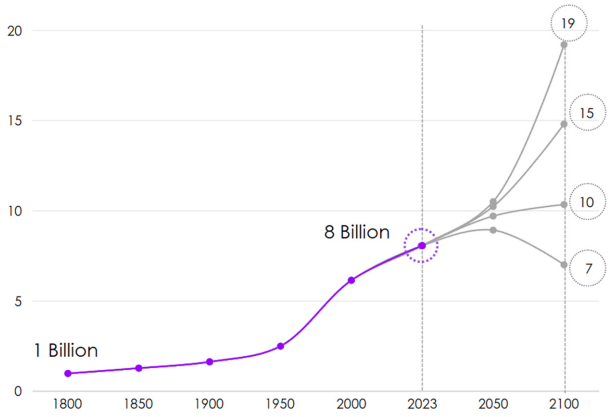


Figure 2. Estimated global population in 2100 (Figures in billion).

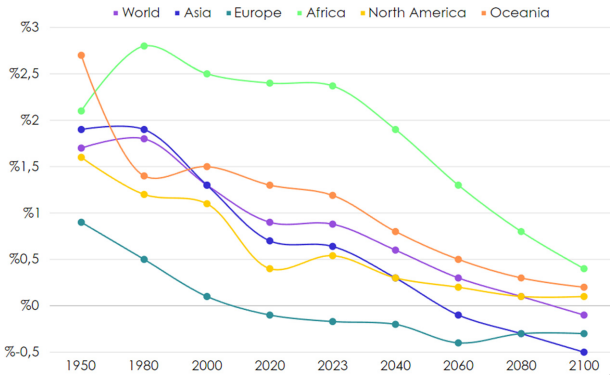


Figure 3. Population growth rate: 1950-2100 (Figures in percentage).

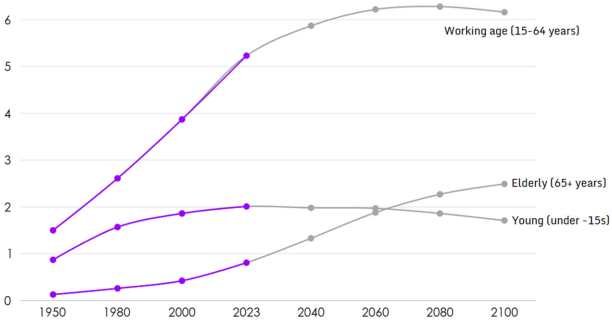


Figure 4. Prediction global population of young, working age and elderly in 2100 (Figures in billion).

tructure adjustment for mobility and smart city needs. The continuous population growth indicates a persistent demand for residential, commercial, and public projects. The expected increase in the elderly population indicates a need for specialized facilities such as healthcare centers. The integration of age-friendly environments into smart buildings, communities and cities is crucial to the promotion of living spaces that are suitable for different age groups. Given all these factors, how will architecture and construction evolve by the year 2100? The most important need of the growing population will be the global housing (Figure 5). By 2021, around 8 million individuals or families will be living with others, while only 3.7 million homes will be available to rent or buy, creating a shortfall of 4.3 million housing shortage. With insufficient homes for millions, the housing market can be likened to a high-stakes game of musical chairs. The crisis is having a disproportionate impact on families on low incomes, with 68 percent of this group living in shared accommodation. The shortage is particularly acute in the more expensive cities along the coast. Researchers suggest that the shortfall in new construction could be alleviated by speeding up planning permission, removing parking requirements, providing tax incentives to regenerate under-utilized housing stock and expanding affordable housing trust funds.

The national housing shortage is caused by combined factors, including high costs and significant regulatory barriers. Innovative construction and strategic policy reform offer viable solutions to this pressing problem. States and cities have launched initiatives to stimulate housing production.

The housing crisis in the United States, shown in Figure 5, was foreseen more than half a century ago and can be traced back to declining productivity in the construction industry, which has negatively affected both the industry and citizens. The necessity for governmental leadership at the national level to increase productivity in the construction sector is clear. To achieve this, governments must review traditional practices and legal constraints in the sector, and institute incentives for more effective and innovative solutions. These policies should not only be punitive bu olsa constructive, encouraging stakeholders in the construction industry towards higher productivity and sustainable growth. Proactive governmental efforts towards improving the construction sector can significantly contribute to the development of national economies and the well-being of societies.

Although the promise of modular construction in terms of speed of delivery and cost effectiveness remains undeniable, its uptake has been slow. Modular construction represents only 6% of the total construction landscape in the United States. This com- pares with countries such as Japan, which uses prefabricated elements in around 15% of residential buildings, and Sweden, which boasts an impressive 80%. To improve efficiency and accelerate progress in the construction industry, the adoption of technological innovations such as Building Information Modelling (BIM) and Artificial Intelligence (AI), as well as targeted regulatory reforms, will be crucial.

2. Changing Roles in the Construction Sector: Adaptation, Innovation, and Technological Integration

Under the pressure of rapid and sustainable construction demands, the industry is being forced to adapt to new skills and integrate technological innovations.

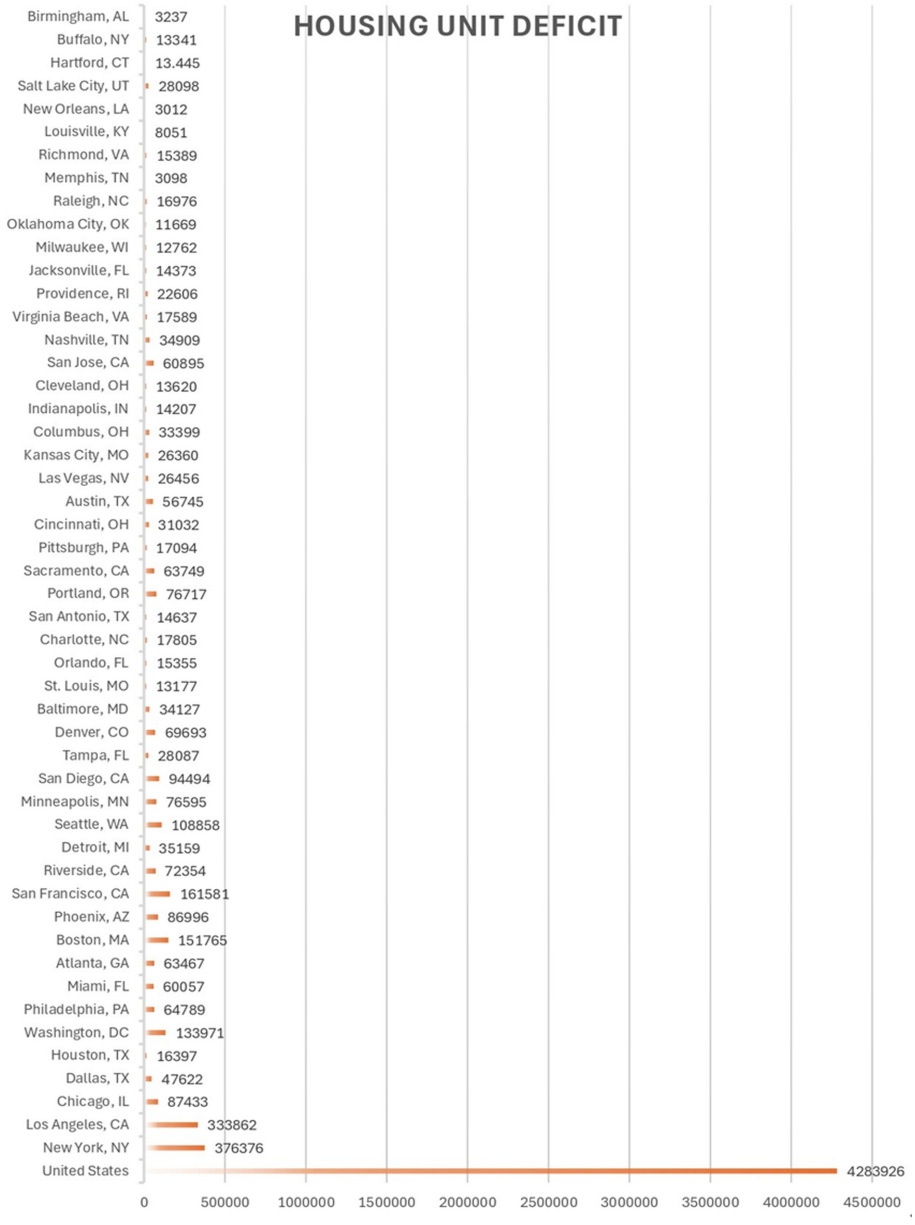


Figure 5. The U.S. cities with the biggest housing shortage.

Traditional construction tools and methods are evolving at each stage of the process. The chart below illustrates the potential role and integration of artificial intelligence in different phases of project development.

The necessity for AI in construction is evident. Firstly, there is a labour shortage, scarcity of materials and resources, as well as a lack of experience in transitioning to the new generation, all which contribute to the urgency for rapid construction. In the early phases, AI can assist in identifying usable land and promptly applying code-related requirements to create feasibility studies, thus expediting the approval process for potential investment and development sites. Architects can leverage AI tools to generate design concepts, testing ideas while simultaneously analyzing code requirements. Furthermore, there are opportunities to automate documentation for construction needs. As the project progresses to the pre-construction phase, AI can aid general contractors in efficiently scheduling resources, teams, and site usage. Additionally, AI can predict potential safety concerns and highlight areas for improvement based on previously collected project data. Another area where AI support is anticipated is during operations and facility management, by analyzing real-time data received from buildings.

The typical procedural framework of a project is as follows: (Figure 6) Typically, the sequence of a project process is expected to follow the lifecycle shown above (Figure 6). But this sequence may change as the project progresses (Figure 7). It is observed that artificial intelligence is used in different design and construction

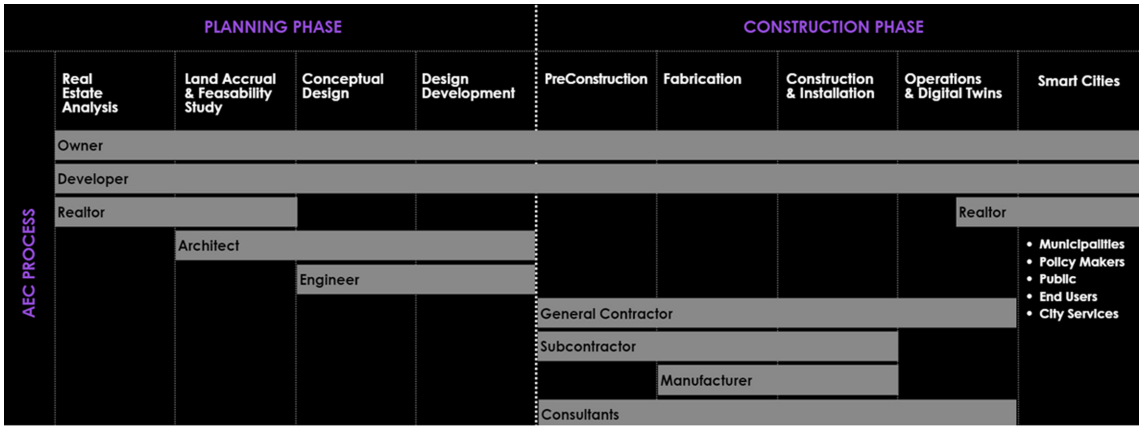


Figure 6. Typical project lifecycle- Design-Bid-Build.

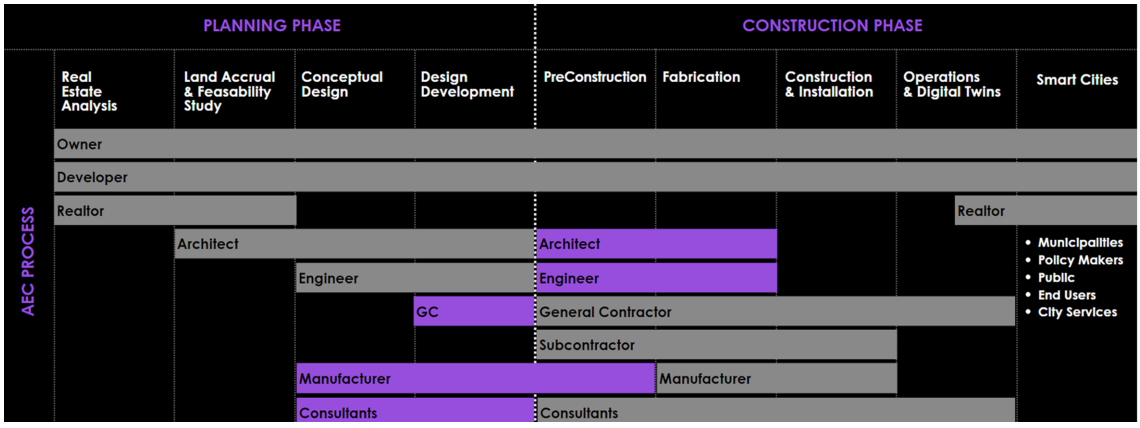


Figure 7. Evolving roles and responsibilities- Design- Build.

phases today (Figure 8).

Manufacturing companies must participate in the early stages of the design process due to the increasing popularity of Design for Manufacturing processes, including modular and timber buildings. This proactive involvement is crucial in reducing the need for design alterations during pre-construction phases. This flexibility is crucial for better adaptation to the project's needs and evolving conditions and is a key aspect to consider for effective project management.

The construction industry employs a variety of software and techniques, one of which is Building Information Modelling (BIM). Architectural design is frequently accomplished with programs such as Revit, Autocad and Bluebeam, while structural design relies on Tekla Structures, Advance Steel, and Robot Structural Analysis. Navisworks, Synchro, and BIM 360 are commonly used for project management and coordination, facilitating effective collaboration. STAAD Pro and Plaxis are the preferred software for structural analysis, soil mechanics and BIM, respectively. Visualization and animation are achieved through the use of tools such as 3Ds Max and SketchUp, while infrastructure design is supported by Civil 3D and Bentley Systems suite. CATIA and 3D experience platform are employed for product design, engineering and collaborative simulation. In addition these, 3D printing is being used in construction to make complex structures and components quickly, it can also be used to make buildings in new ways and to reduce waste, also can used to make buildings more cheaply.The choice of software program or method should be based on the project's characteristics and requirements.

3. Examination of Prefabrication and Modular Construction Methods: The 'Kit of Parts' Concept and Cost-Effectiveness Analysis

Some regions require entirely new urban development and construction, while others focus on revitalizing existing infrastructure.

Whether pursuing new architectural endeavors or renovating existing structures, it is imperative that every building incorporates a renewable strategy. As cities grow, construction must use sustainable materials and methods to reduce its impact on the environment and save energy. Prioritizing renewables minimizes environmental impact and ensures a sustainable future. Renewable integration is a fundamental principle in modern architectural and

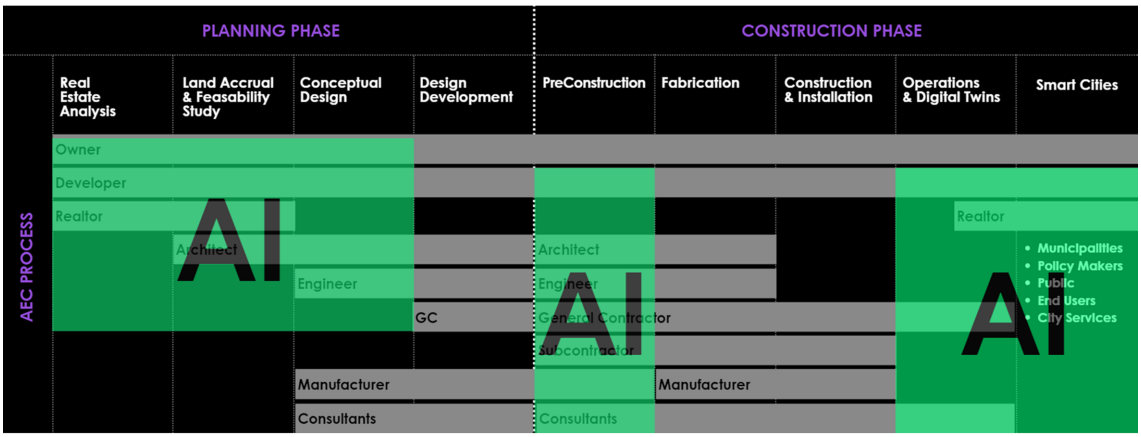


Figure 8, Technological integration.

urban development. In this context, it is likely that two different strategies need to be distinguished.

For rapidly expanding regions, the implementation of "fast & sustainable construction" is required. Conversely, for countries where population growth rates are stabilizing or declining, "adaptive reuse", that is, repurposing existing structures for different functions rather than constructing new ones, appears to be the most viable option (Figure 9).

The importance of modular building concepts that allow for the assembly or disassembly of components to adapt spaces and functions. The concept of a "kit of parts" (Figure 10) not only facilitates resource management, but also leverages advances in Design for Manufacturing and Assembly (DFMA) technologies, thereby enhancing sustainability throughout the building's lifecycle.

Adaptive construction strategies prioritize the holistic use of resources and environmental resilience. The incorporation of modular design and Design for Manufacture and Assembly (DFMA) technologies is supported by empirical evidence demonstrating their efficacy in reducing waste and optimizing resources, thereby facilitating the construction of eco-friendly buildings.

The modular design of components enables efficient material usage through standardization, facilitating easy assembly, disassembly, and reuse. This reduces the need for new materials, minimizing waste generation in construction. DFMA technologies streamline manufacturing and assembly processes, optimizing resource use by designing components that require minimal energy and raw materials. Modular construction and DFMA techniques often shorten construction time, limiting energy consumption and pollution.

Design for manufacturing and assembly (DFMA) necessitates collaboration between designers and manufacturers at the earliest stages of the design process. This ensures that designs align with the capabilities of the manufacturing process. While initially perceived as a limitation on design, this approach allows for parallel production and early material procurement, enhancing project efficiency. Advanced tools enable the design of complex projects with manufacturer input, providing both design flexibility and production feasibility. This shift from separate design and construction responsibilities to a more integrated approach may even empower architects to act as master builders, offering them the option to be concept designers or hands-on builders, depending on their risk tolerance and project vision.

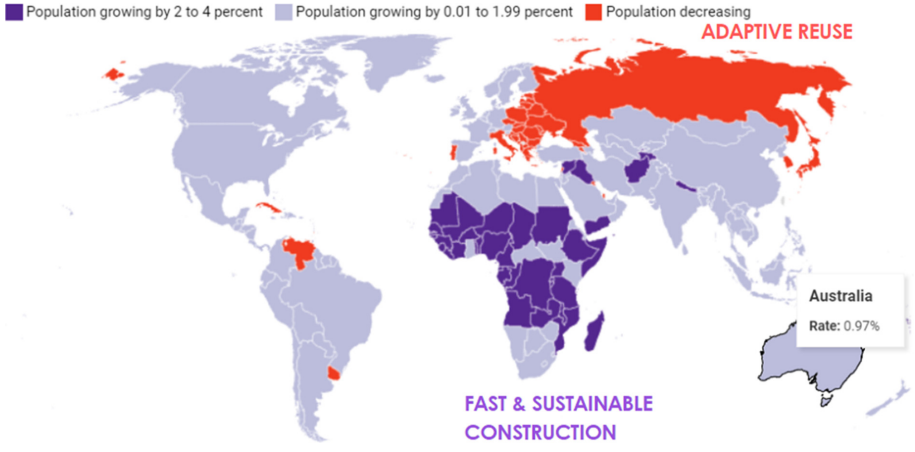


Figure 9. Population growth and shrinking.

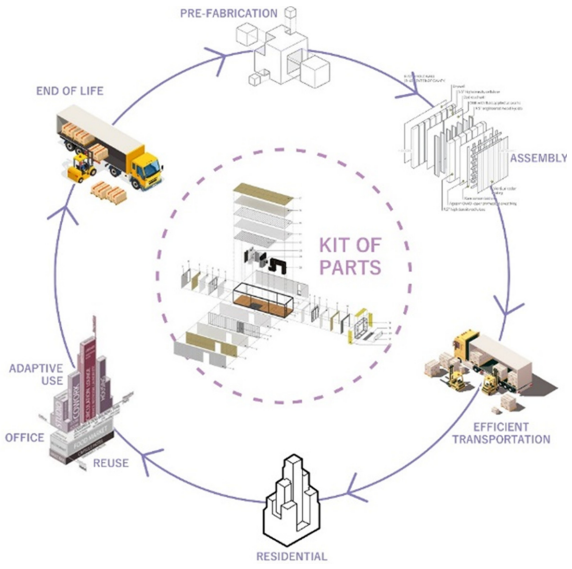


Figure 10. The "Kit of Part" concept.

4. Conclusion

This article suggests that it is urgent to address both current and long-term needs in the construction industry. It also highlights the significant impacts of demographic shifts, both in the short and long term, and proposes innovative solutions. The construction approach aims to address critical aspects such as cost, speed, and sustainability, offering a potential remedy to the industry's challenges.

Furthermore, it is recommended that industry roles be comprehensively restructured to facilitate end-to-end solutions. The integration of artificial intelligence throughout various construction phases is considered crucial for optimizing processes and outcomes. Finally, the exploration of the 'Kit of Parts' concept, along with Design for Manufacture and Assembly (DFMA) and modular construction, is seen as a promising pathway towards enhancing construction efficiency and long-term resilience. By implementing these strategies, it is possible to create a construction industry that is more resilient, adaptable, and future proof.

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