34th Annual INCOSE international symposium

hybrid event

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Food Transformation (FX): A Systems Engineering Approach to Elevate Value through Cooking Recipe Design with Alternative Proteins

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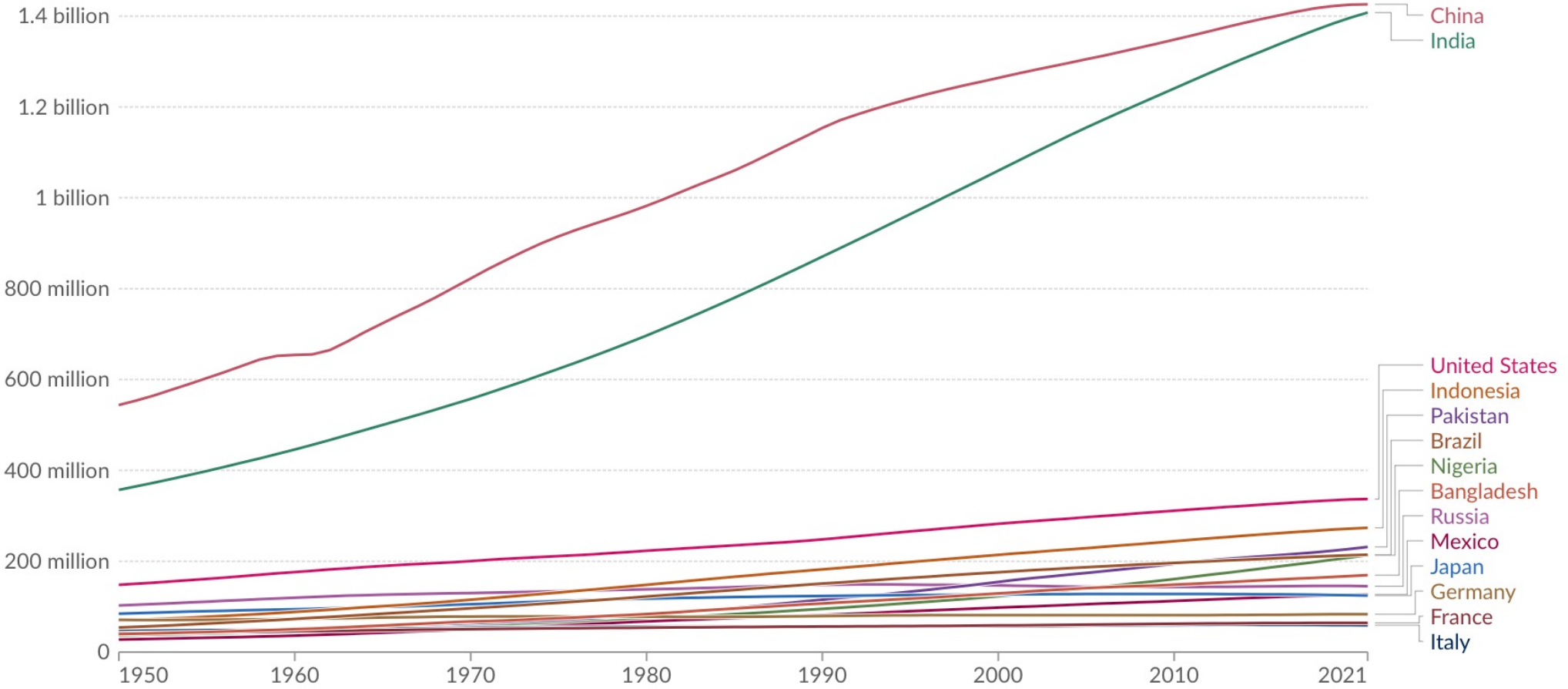
Increase in World Population and Rising Food Demand



(Ref: Our World in Data, https://ourworldindata.org/population-growth, Data source: United Nations, World Population Prospects (2022))

Increase in World Population and Rising Food Demand

- The issue of food supply and demand is regarded as an urgent challenge, as the conventional food supply system alone cannot meet the food demand of the growing population.

https://jbpress.ismedia.jp/ts/thermofisherscientific/6/

Increase in World Population and Rising Food Demand

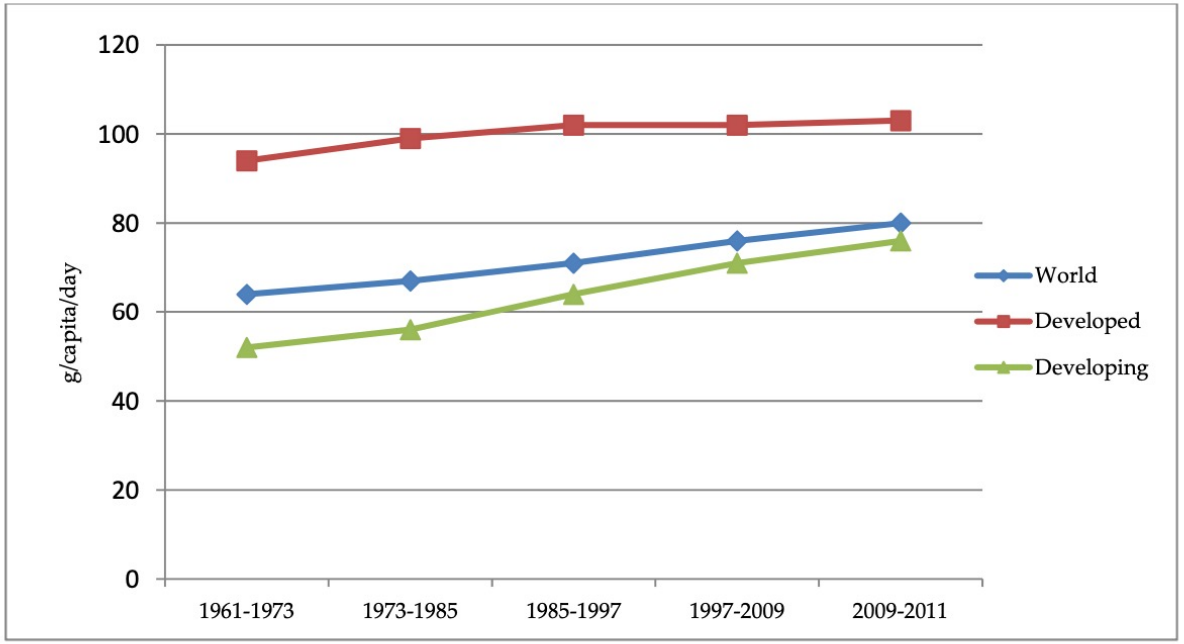


Figure 1. Evolution in protein consumption per capita (g/capita/day). Source: Author's analysis based on food balance and population data obtained from http://faostat3.fao.org.

- Protein is one of the five major nutrients that are essential for human life
- carbohydrates, fats, proteins, minerals, and vitamins

(Ref: Henchion M, Hayes M, Mullen AM, Fenelon M, Tiwari B. Future Protein Supply and Demand: Strategies and Factors Influencing a Sustainable Equilibrium. Foods, 6(7):53, 2017. https://doi.org/10.3390/foods6070053)

Protein ingredients

- In recent years, the demand for protein ingredients has increased dramatically.
- The global protein ingredients market was valued at US$38 billion in 2019 and is projected to grow at a rate of 9.1% from 2020 to 2027 (Grandview Research, 2020).
- Consumption of animal protein has gradually increased,
- The overall interest in protein is expected to drive substantial growth in the market for plant-based protein ingredients.

https://www.thoughtco.com/proteins-373564

Protein ingredients

- Furthermore, new approaches are being explored to replace conventional livestock-centered protein supplies.
- Various research and development efforts are underway, including the use of insect-based diets, cultured meat, and advancements in animal welfare

(Liu, F., et al., 2022; Fasolin, L.H., et al., 2019).

https://alternativeproteinsglobal.com

https://mindthegraph.com/blog/insect-protein/

Research Background

Alternative Proteins

- Alternative proteins are obtained from resources other than those derived from plants and animals, and are considered to have low environmental impact and high sustainability (Grossmann, L. and Jochen Weiss, 2021).

- Food producers are seeking to understand how these plant-based proteins can partially or wholly replace traditional plant and animal protein ingredients in food or plant-based meat-alternative products to deliver optimal nutrition, flavor, and functionality (B Pam Ismail, et al., 2020).

Alternative Proteins

- Hence, it is crucial to showcase that novel plant proteins possess can be designed architecture equivalent or superior functions compared to their existing proteins.

https://spaceshipearth.jp/alternative-protein/

Recipe design and systems engineering

- Recipe design has long been studied in the fields of culinary science and nutrition.

- Food can be decomposed into elements at the level of ingredients and food components, and new approaches such as molecular cooking methods have been developed in recent years to decompose food into elements at a more detailed molecular level.

Cooking No-Recipe Recipes
By Sam Sifton
Ten Speed Press

Recipe design and systems engineering

- Why is it beneficial to use systems engineering in the design of recipes using plant-based proteins?
- The reason is that the method of recreating a conventional dish using plant-based protein is not limited to mere substitution of ingredients.

Systems Engineering Approach

Cooking No-Recipe Recipes
By Sam Sifton
Ten Speed Press

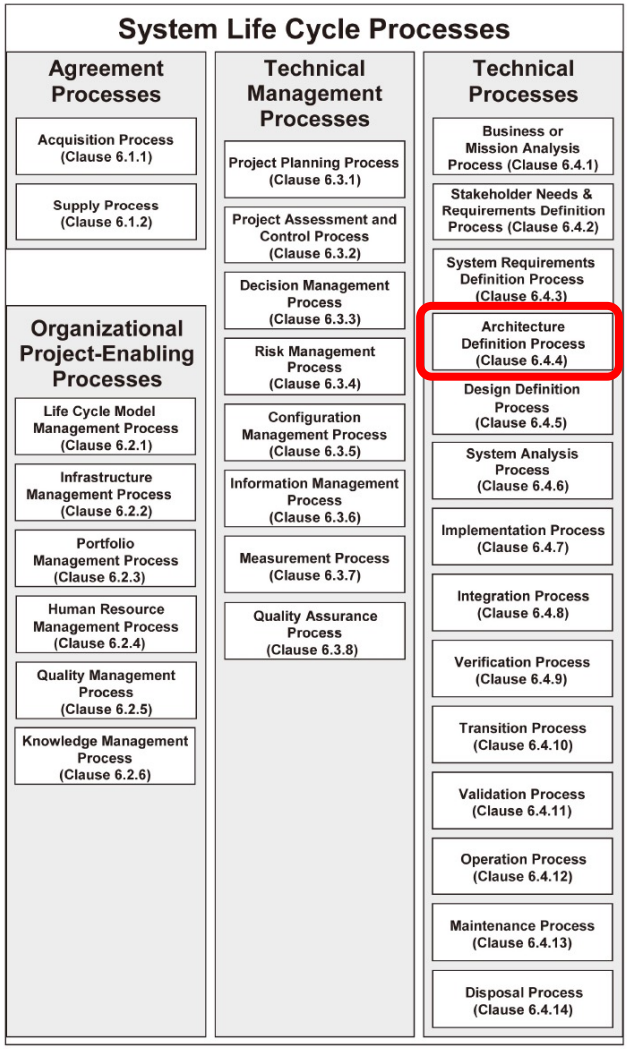
Research Objective

- This research aims to develop a concept of cooking recipe design method using systems engineering to realize same characteristics of conventional dishes using meat using plant-based foods.

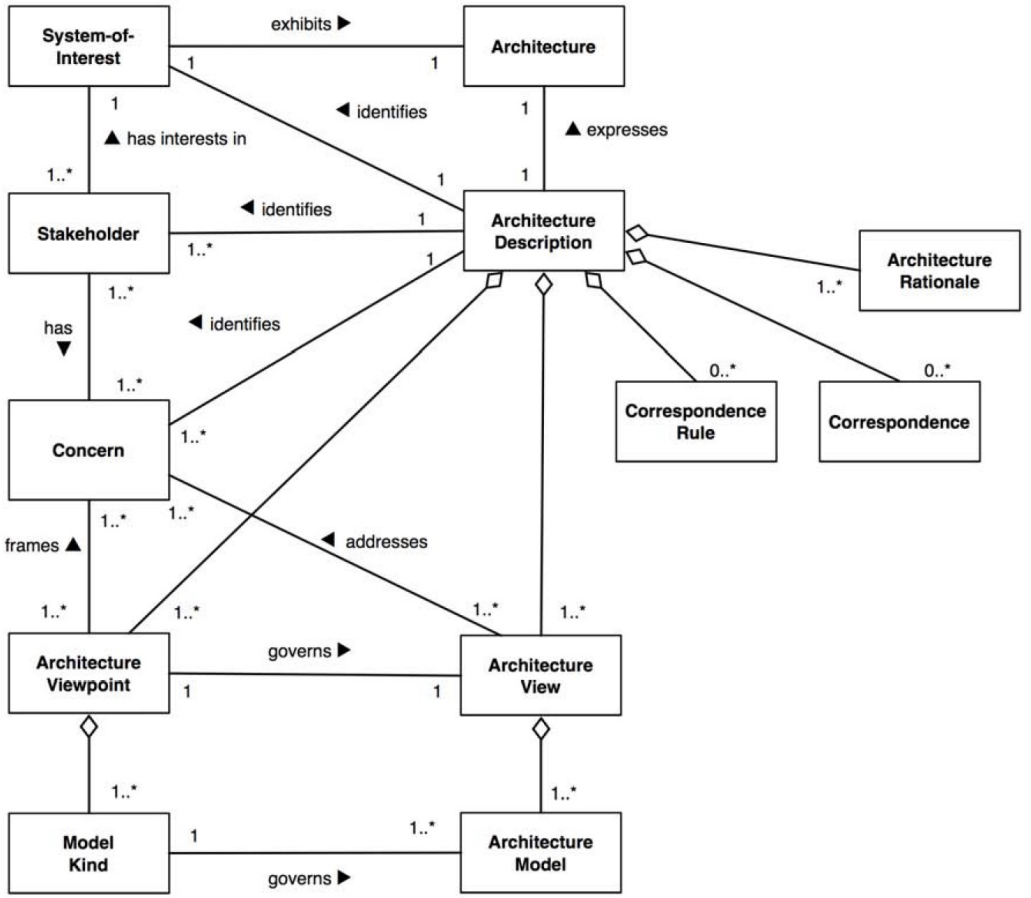
- In particular, we aim to develop the method for FX (Food Transformation) in the context of value creation in DX (Digital Transformation).

- In this presentation, we present our ongoing research projects, including a recipe for hamburgers made with plant-based foods.

System Architecture



Source: ISO/IEC/IEEE15288-2015
System life cycle processes

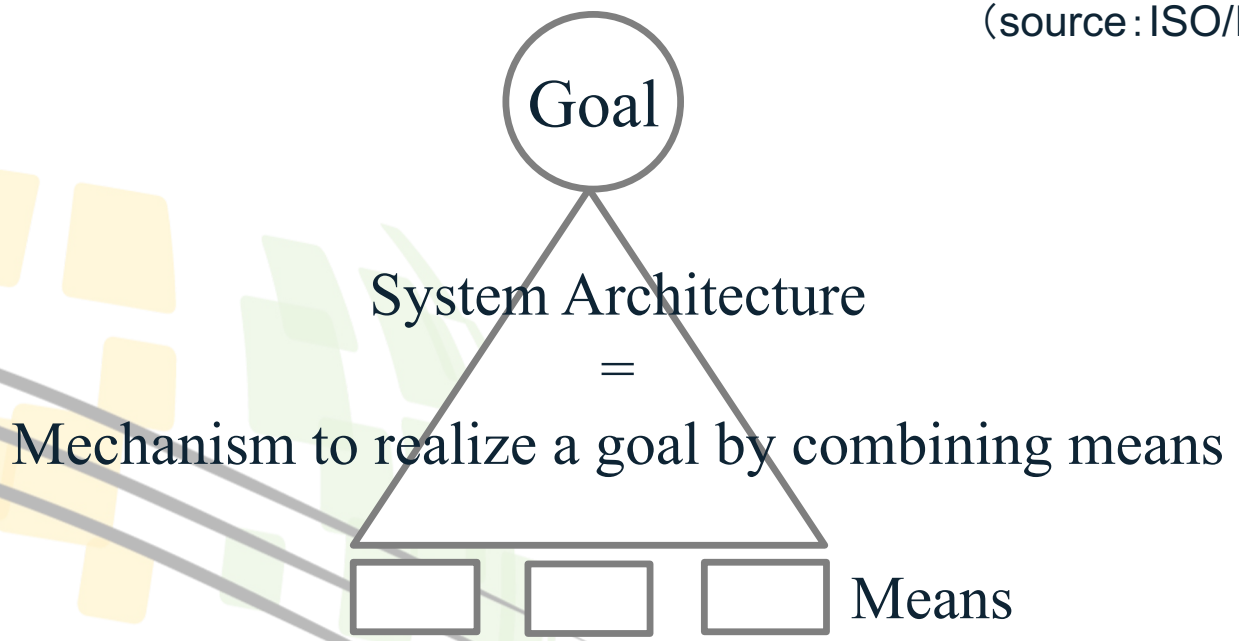


Source:
ISO/IEC/IEEE42010-2011
Architecture Description

Definition of System Architecture

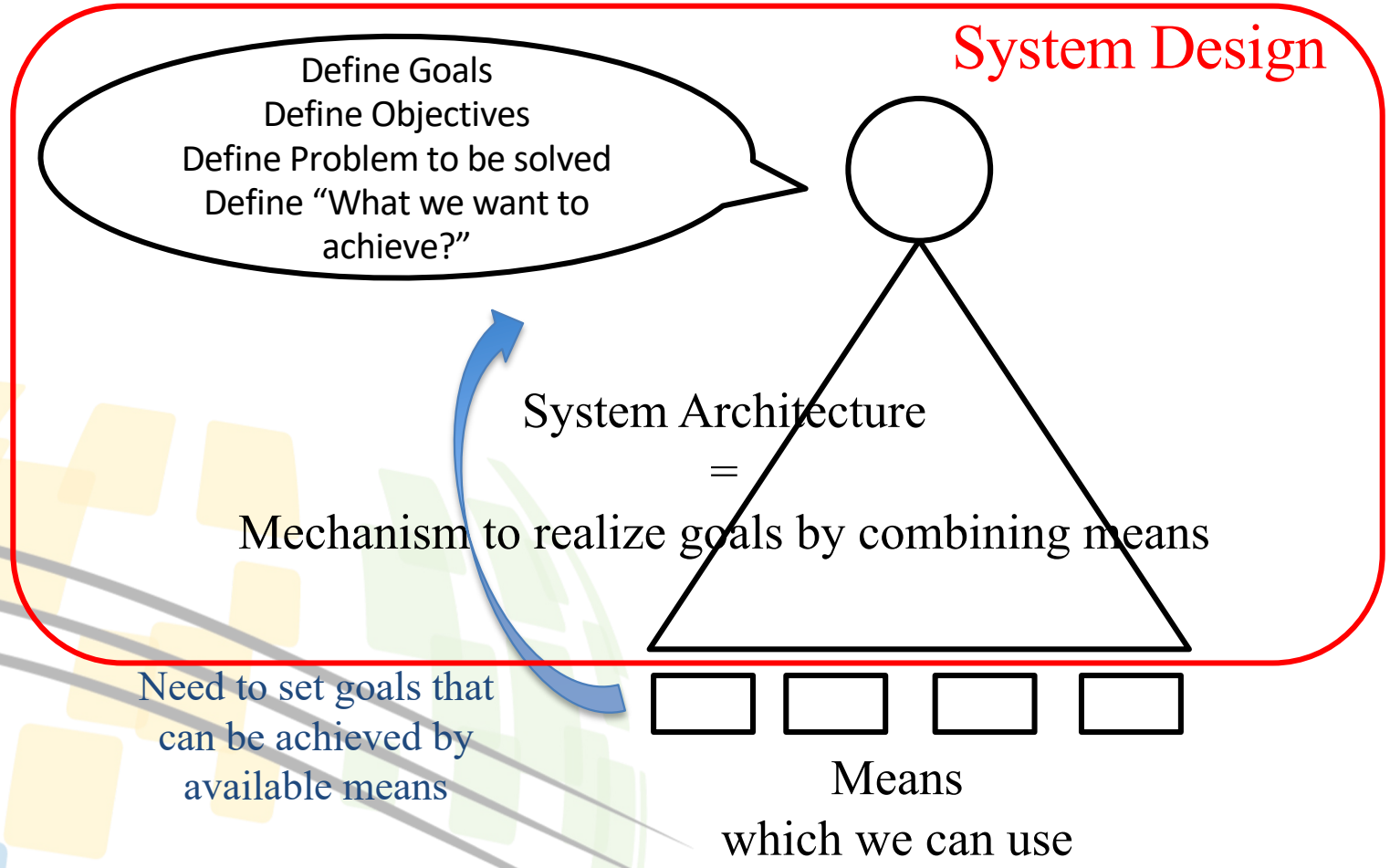
fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution

（source：ISO/IEC/IEEE 42010-2010)



(S Shirasaka, Manufacturing Approaches for the Digital Age, The Robot Revolution & Industrial IoT International Symposium 2022)

What is System Design



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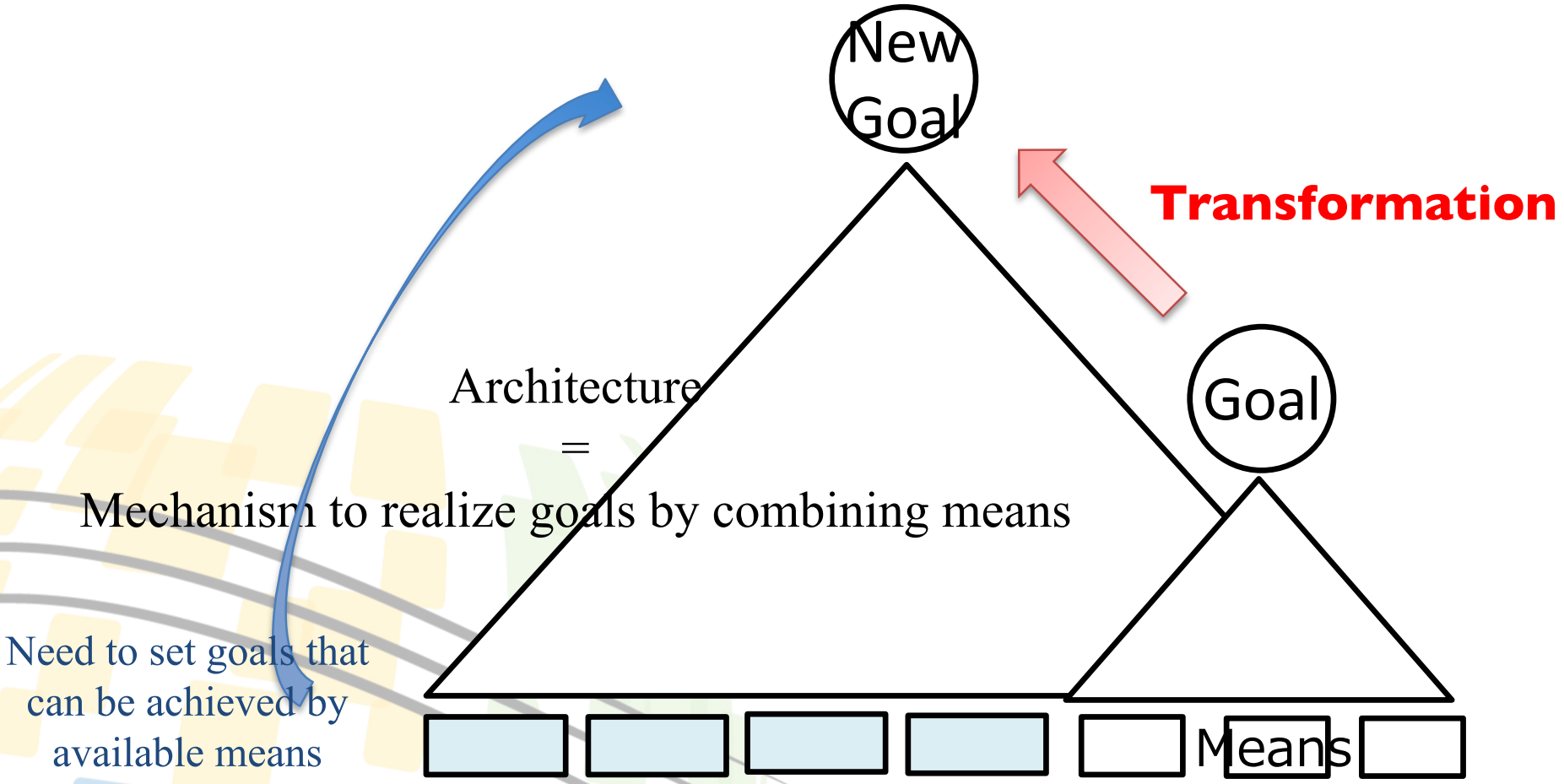

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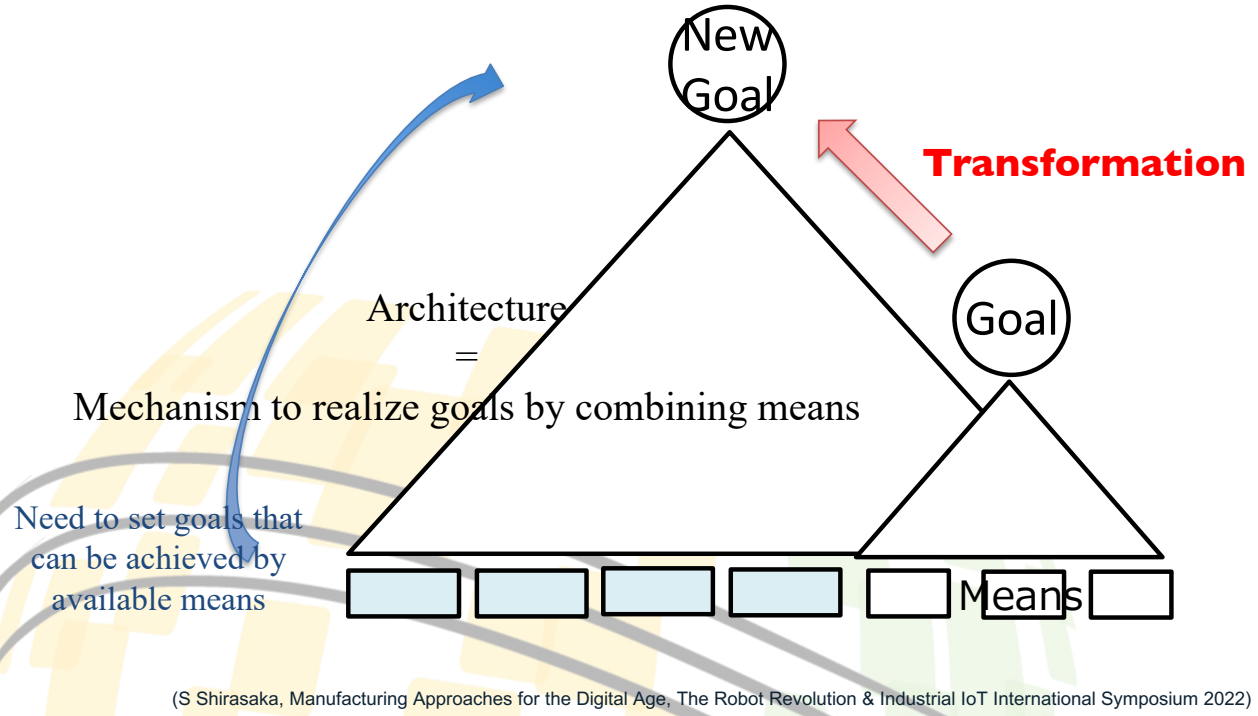
Food Recipe Design



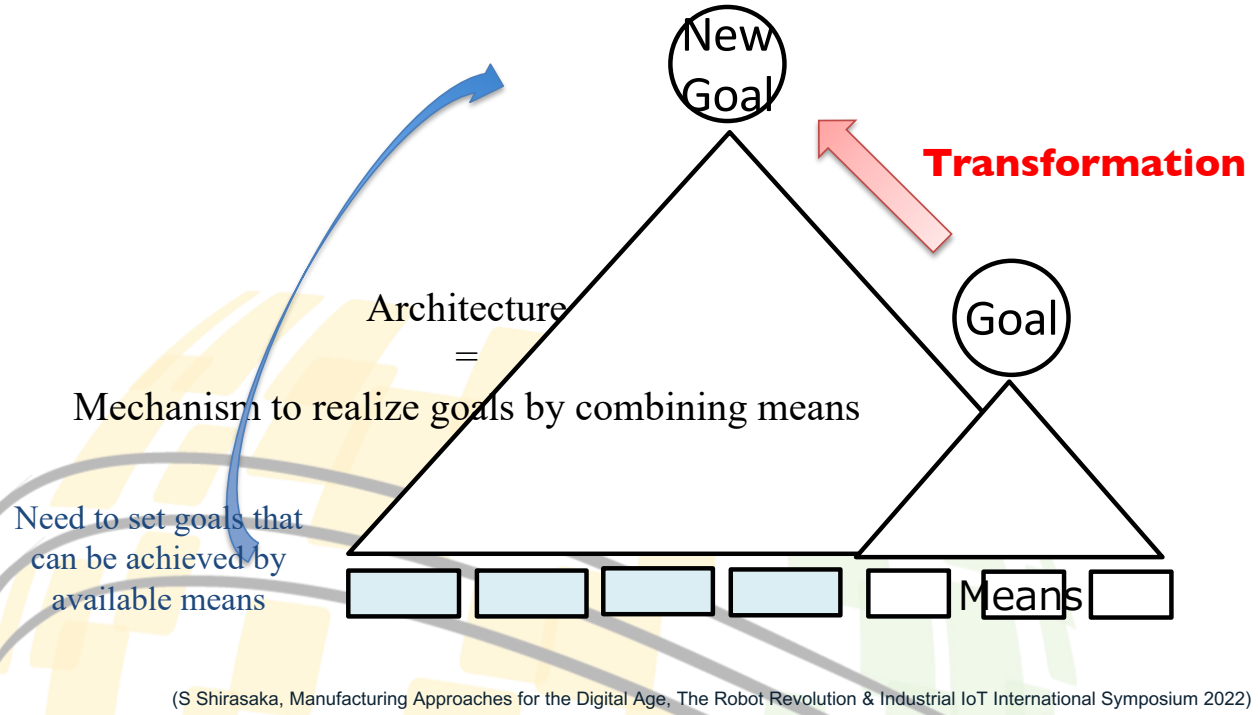
(S Shirasaka, Manufacturing Approaches for the Digital Age, The Robot Revolution & Industrial IoT International Symposium 2022)

1. The replacement of existing ingredients and means

2. The replacement of existing ingredients and means
   + architecture design

3. The replacement of existing ingredients and means
   + architecture design to achieve new goal

Food Recipe Design



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1. The replacement of existing ingredients and means

Digitization

2. The replacement of existing ingredients and means
+ architecture design

Digitalization

3. The replacement of existing ingredients and means
+ architecture design to achieve new goal

Digital Transformation

Case1: hamburger steak recipe

Ingredients:

- 500g ground beef
- 1 small onion, finely chopped
- 1 egg
- 2 tablespoons breadcrumbs
- 2 tablespoons milk
- 1 tablespoon Worcestershire sauce
- Salt and pepper to taste
- Olive oil or cooking spray

https://www.kurashiru.com/articles/a2bc0c66-d171-4565-8048-a491cc1b7493

Case1: hamburger steak recipe

Instructions:

1. In a mixing bowl, combine the ground beef, finely chopped onion, egg, breadcrumbs, milk, Worcestershire sauce, salt, and pepper. Mix well until all ingredients are evenly incorporated.

2. Divide the mixture into equal portions and shape them into oval or round patties, about 2 cm thick.

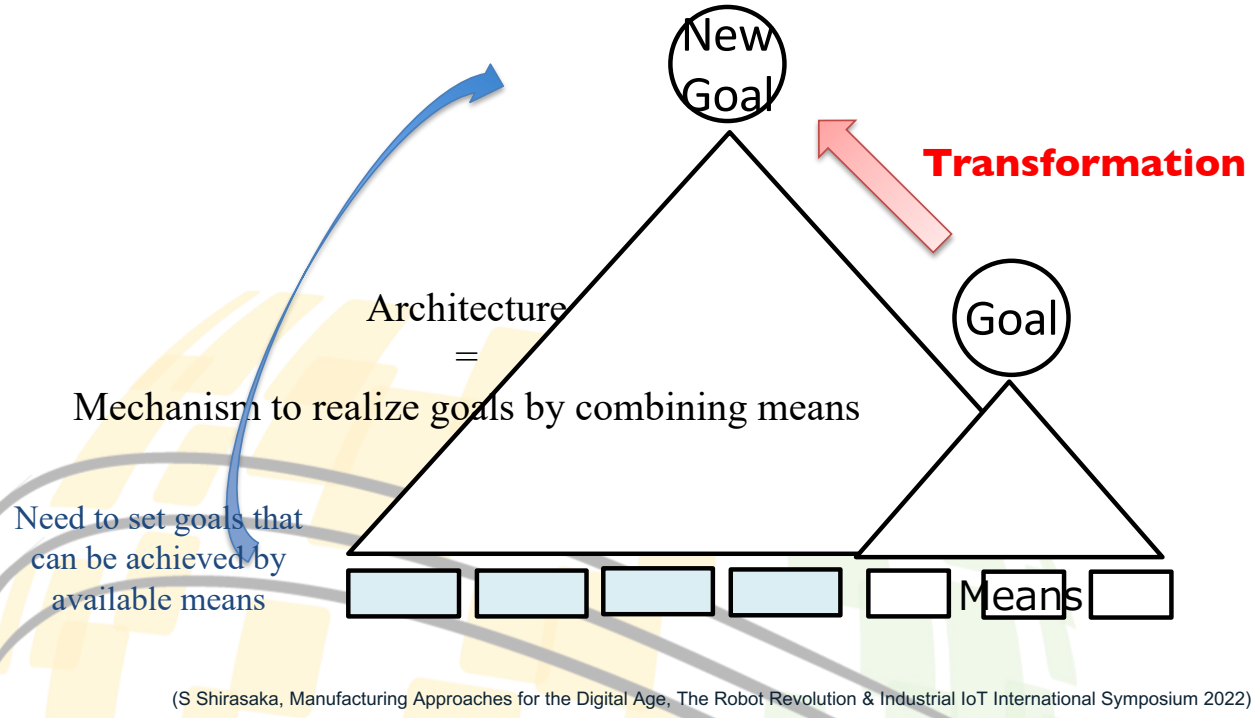
3. Heat a frying pan over medium heat and add a little olive oil or cooking spray to prevent sticking.

4. Carefully place the hamburger patties in the pan and cook for about 5-7 minutes on each side, or until they are browned and cooked through.

5. Once the hamburgers are cooked, remove them from the pan and let them rest for a few minutes before serving.

6. Serve the hamburgers with your favorite sides such as mashed potatoes, steamed vegetables, or a fresh salad. Enjoy your homemade hamburgers.

Case1-1: hamburger steak recipe



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1. The replacement of existing ingredients and means

Foodiation

Digitization

step1
Determine alternative beef ingredients.

step2
Process redesign for the range of processes affected by ingredients changes.

step3
Review and arrange seasoning and ingredients.

Case1-2: hamburger steak recipe

A time when hunk of meat steaks were expensive and not common to eat

The hamburger originated when small pieces of meat were gathered together to resemble a hunk of meat instead of a hunk of meat.

https://www.zkai.co.jp/saponavi/el/series/35990/

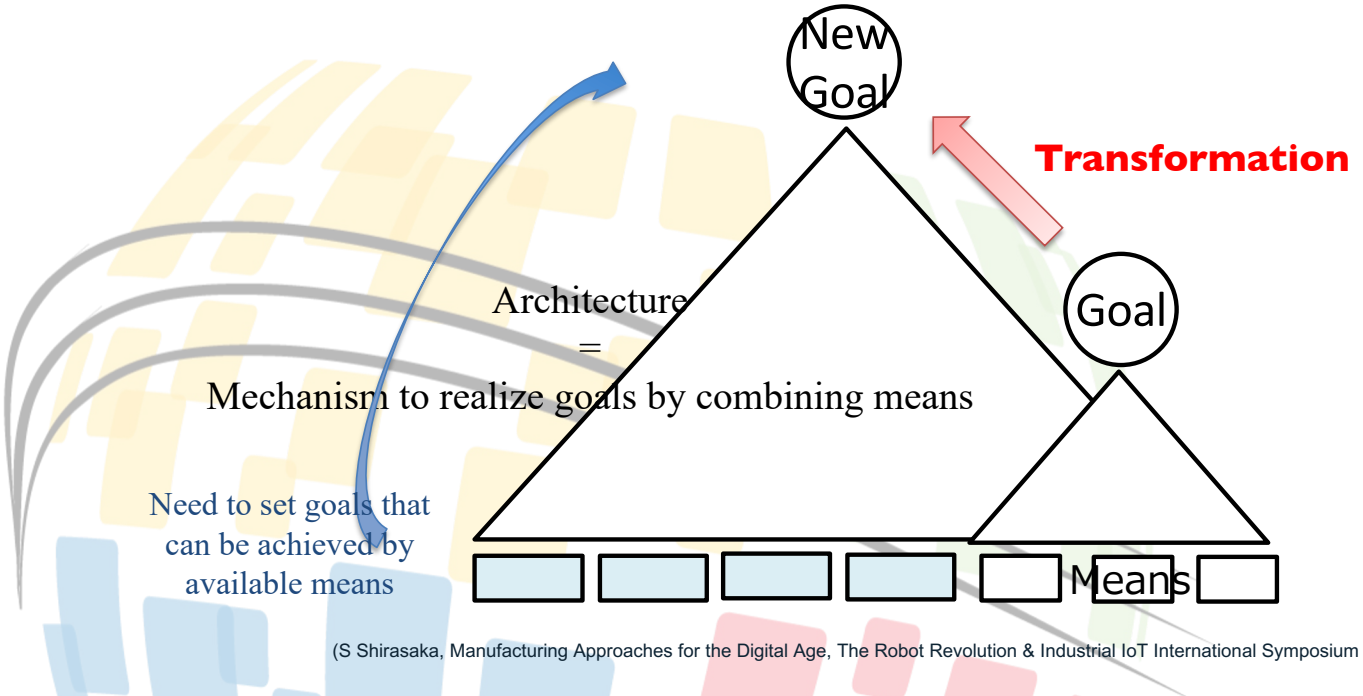
https://www.orangepage.net/ymsr/kihon/hatena/posts/2065

Case1-2: hamburger steak recipe

Goal: To eat hunks of meat.

For this goal, the main ingredient is given
The sub-materials are designed for eating hunks of meat.

https://www.zkai.co.jp/saponavi/el/series/35990/



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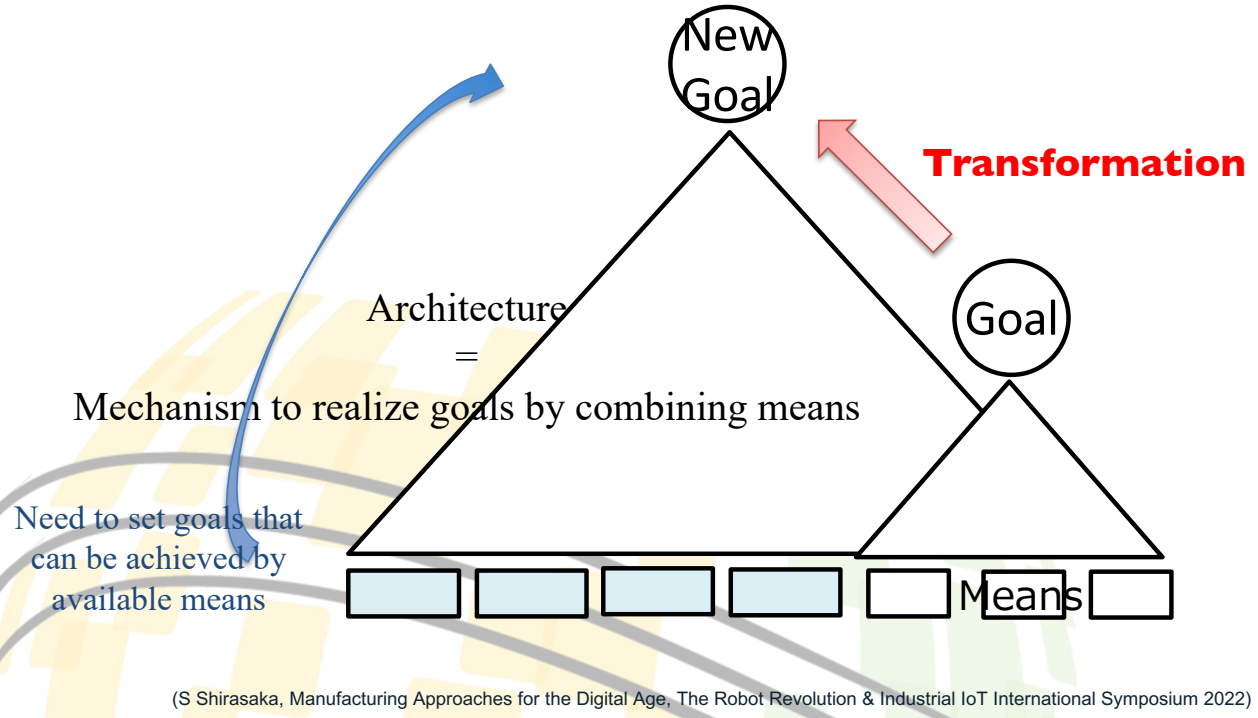
https://www.orangepage.net/ymsr/kihon/hatena/posts/2065

Case1-2: hamburger steak recipe



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2. The replacement of existing ingredients and means
   + architecture design

Foodilization

Digitalization

step1
Check conventional requirements for hamburger steaks.

To eat scrap meat in the form of shaped and lumpy meat

step2
Design the necessary processes and materials to shape the material to be substituted like a piece of meat.

Case1-2: hamburger steak recipe

Sample A (Plant meat hamburger steak with dried shiitake mushroom broth)

Ingredients:

dried soybeans (100 g),
onion (about 90 g),
dried shiitake mushrooms (5),
potato starch (2 tablespoons),
water (30 ml),
nutmeg (1/4 teaspoon),
black pepper (pinch),
oil (as needed)

(F Tani, Effects of different ingredients and cooking methods in plant meat on reproducibility of livestock meat., graduation research, Ritsumeikan University, 2023)

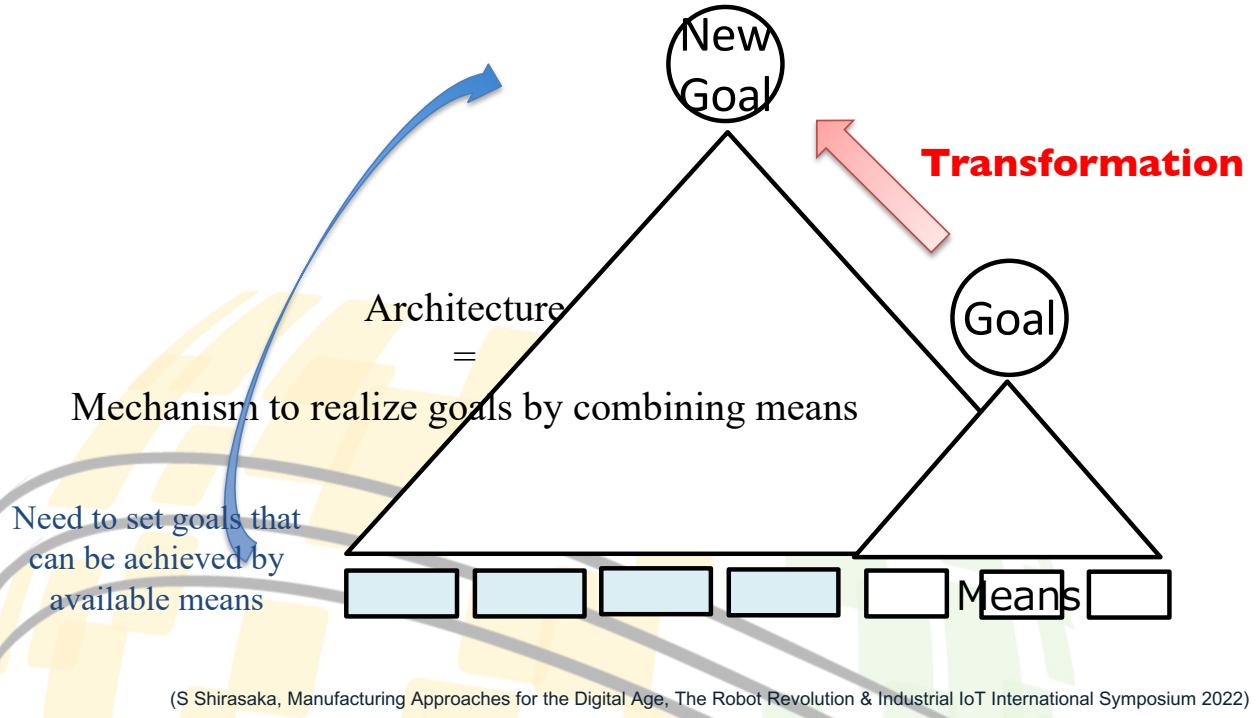
Case2: molecular cooking

Pursues new tastes by capturing ingredients and cooking processes at the molecular level

https://chojumikata.com/coverstory/595/essay

https://bizly.jp/foodtech-moleculargastronomy1/

Case2: molecular cooking



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3. The replacement of existing ingredients and means
   + architecture design to achieve new goal

Food Transformation

Digital Transformation

Designing recipes that were not by systems approach with a top-down approach.

Case3: Tofu recipe in Edo period

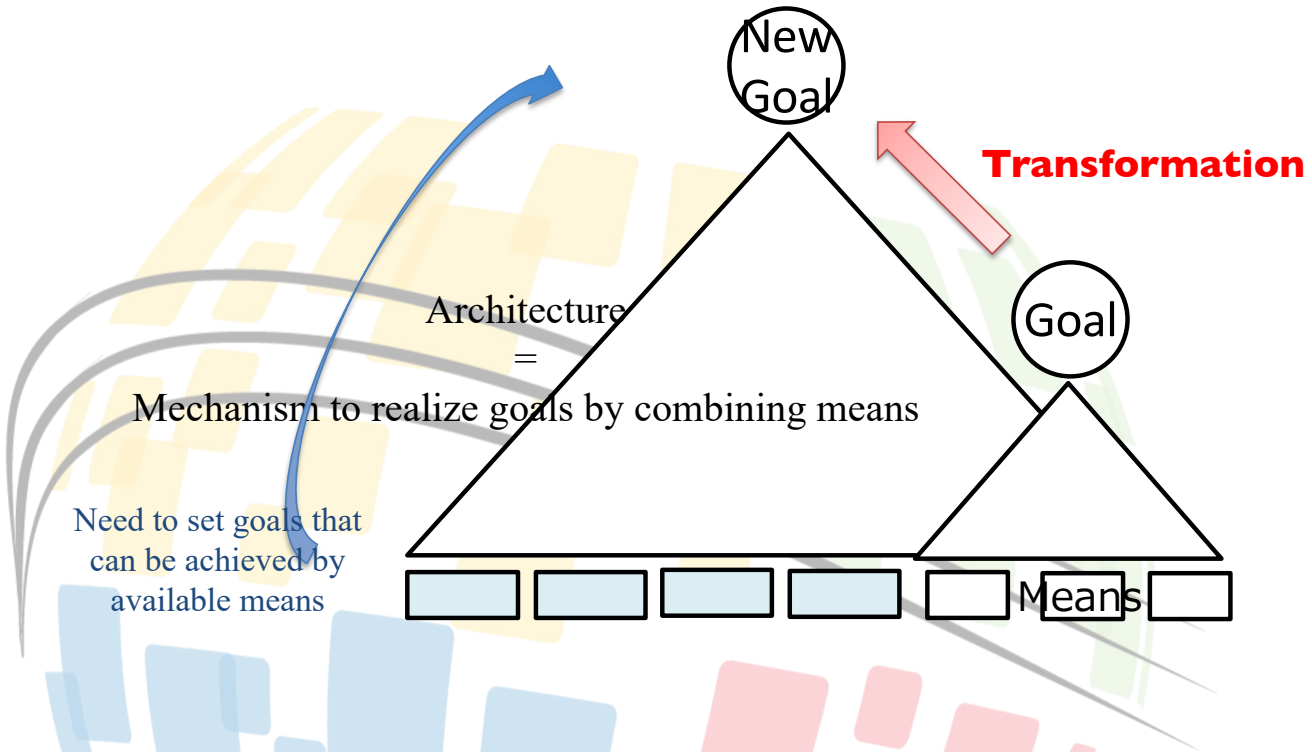
- “Tofu Hyakuchin”, a cookbook published in the Edo period.
- The ambiguity of the description in the recipe is analyzed using "Fuhafuha Tofu," which is de-scribed in number 21 of the book

Ref) Tofu Hyakuchin”（National Diet Library Digital Collections）

(T Nonaka, et al., Systems engineering analysis for cooking recipes from the perspective of work instructions, APMS2021)

Case3: Tofu recipe in Edo period

Regenerate recipes that were not well understood based on recipes with insufficient information, including ambiguity



2. The replacement of existing ingredients and means
   + architecture design

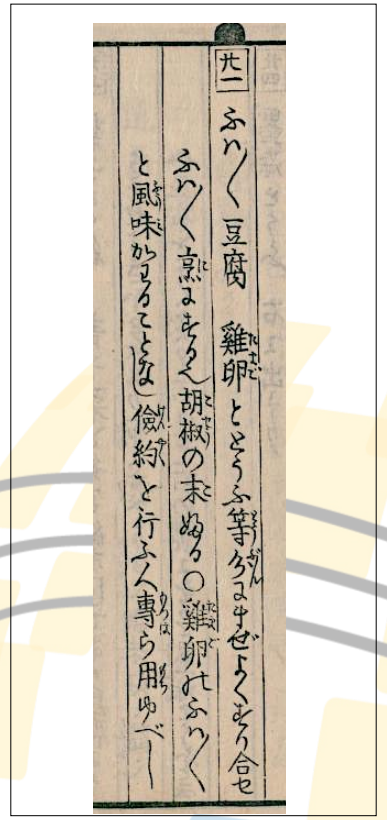
Foodilization

Digitalization

Interpret and redesign the recipe, supplementing the parts that contain insufficient information where clear definitions of means and architecture cannot be confirmed

Case3: Tofu recipe in Edo period

No.21 Fuhafuha Tofu



翻刻

reprinting

廿一 ふは〳〵豆腐 鶏卵ととうふ等分にまぜよくすり合せ
ふは〳〵煮にする也 胡椒の末ふる 〇鶏卵のふは〳〵
と風味かわることなし倹約を行ふ人専ら用ゆべし

現代語訳

translated into modern Japanese

レシピ

①卵と豆腐、同量をさっくりまぜ、その後よくすり合わせます。
②ふわふわに煮ます。
③胡椒をふります。

（ポイント）

卵のふわふわと風味は変わりません。そのため、倹約家は、卵の代わりに豆腐をまぜ入れます。

（材料）

豆腐　卵　胡椒

Recipe

1) Mix eggs and tofu in the same amount, then mix thoroughly.
2) Boil it fluently.
3) Put the pepper.

Note

The egg fluffy and flavor will not change. Therefore, the economical person puts tofu in stead of eggs.

Ingredient

Tofu egg, pepper

(T Nonaka, et al., Systems engineering analysis for cooking recipes from the perspective of work instructions, APMS2021)

Case3: Tofu recipe in Edo period

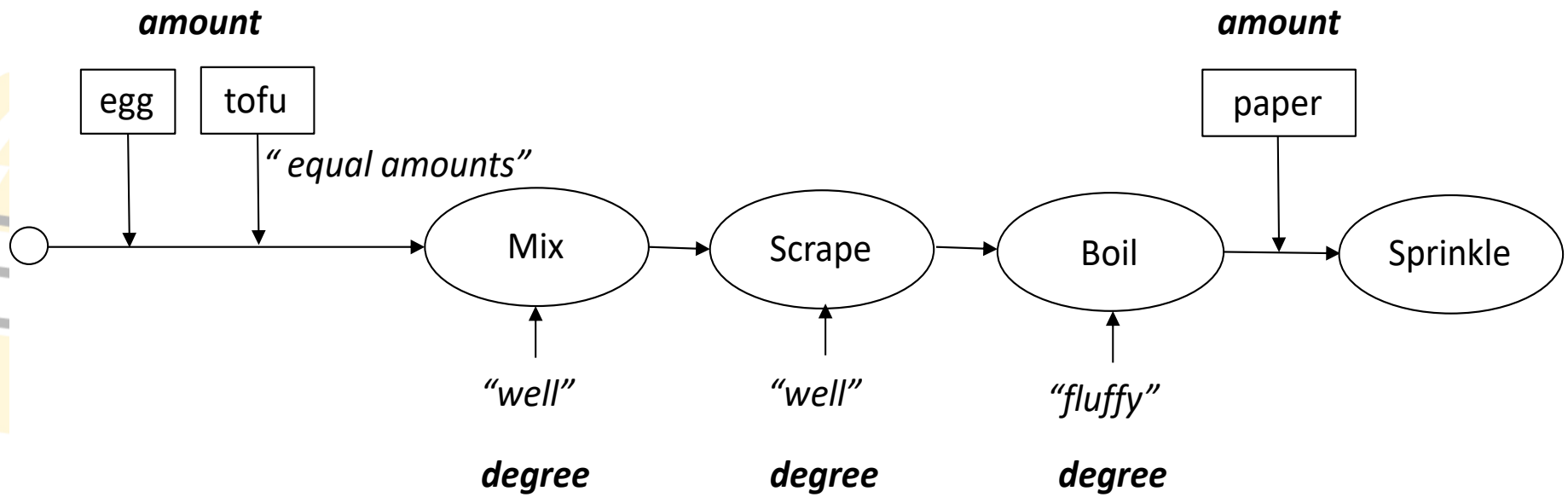
We focus on the textual information. The following steps are used to analyze the text information translated into modern Japanese.

STEP1:
Extraction of information explicitly described in cooking recipes
Extract character strings that are explicitly described in the cooking recipe and divide them into morphemes.
These include noun phrases for ingredients and verb phrases for processes.

(T Nonaka, et al., Systems engineering analysis for cooking recipes from the perspective of work instructions, APMS2021)

Case3: Tofu recipe in Edo period

STEP2: Process description
Describe the process diagram using the extracted morphemes (Figure).
Noun phrases are written as squares, **verb phrases as circles**, and **other words as text**.



(T Nonaka, et al., Systems engineering analysis for cooking recipes from the perspective of work instructions, APMS2021)

Case3: Tofu recipe in Edo period

STEP3: Identifying non-unique information for cooking reproduction
Organize the information that is not uniquely determined when attempting to reproduce the cooking based on the described process diagram. These include the specific amount of food, the amount of heat and mixing, and adverbial ex-pressions such as frequency and degree for verb phrases.

Recipe

1) Mix eggs and tofu in the same amount, then mix thoroughly.
2) Boil it fluently.
3) Put the pepper.

Note

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Ingredient

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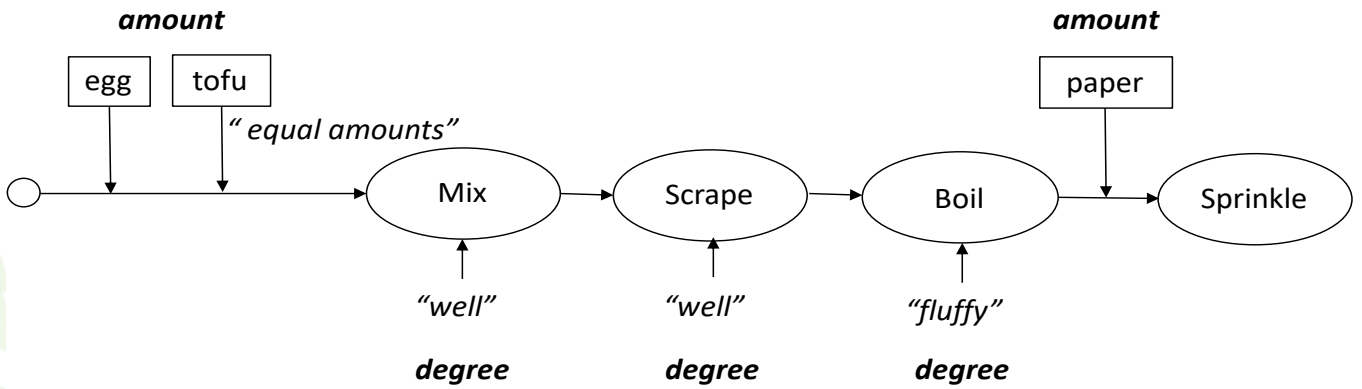
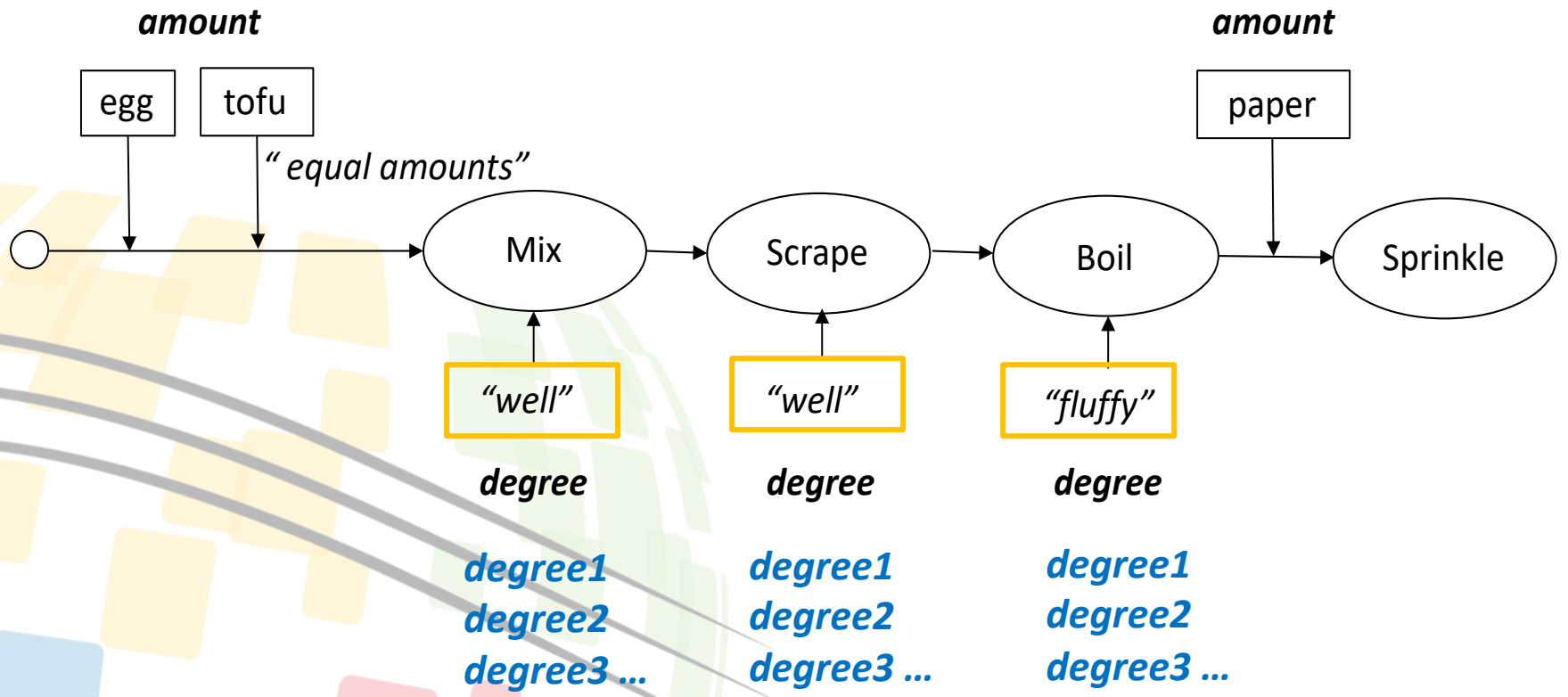


(T Nonaka, et al., Systems engineering analysis for cooking recipes from the perspective of work instructions, APMS2021)

Case3: Tofu recipe in Edo period

When cooking a recipe that **contains ambiguous information**, the cook **needs to estimate the task from the context** and the context before and after as shown in the previous pages.



(T Nonaka, et al., Systems engineering analysis for cooking recipes from the perspective of work instructions, APMS2021)

Case3: Tofu recipe in Edo period

Estimation of ambiguous information

$$\text{Minimize} \quad g = g(\boldsymbol{x}) \quad \text{with respect to } \boldsymbol{x}$$
$$\text{subject to} \begin{cases} \boldsymbol{h}(\boldsymbol{x}) = \underline{\boldsymbol{h}} \\ \boldsymbol{c}(\boldsymbol{x}) \leq \underline{\boldsymbol{c}} \end{cases} \tag{1}$$

For example, in the case of "Fuhafuha Tofu," for the description of "**Fuhafuha**" in the name of the dish, the objective is how to make the finished dish into a **Fuhafuha state**, which is assumed to be a maximization problem of the Fuhafuha state.

In Japanese, "fluffy" means very soft and fluffy that is called “Fuhafuha”.

In other words, it can be regarded as **a problem of maximizing softness and fluffiness**.

(T Nonaka, et al., Systems engineering analysis for cooking recipes from the perspective of work instructions, APMS2021)

Case3: Tofu recipe in Edo period

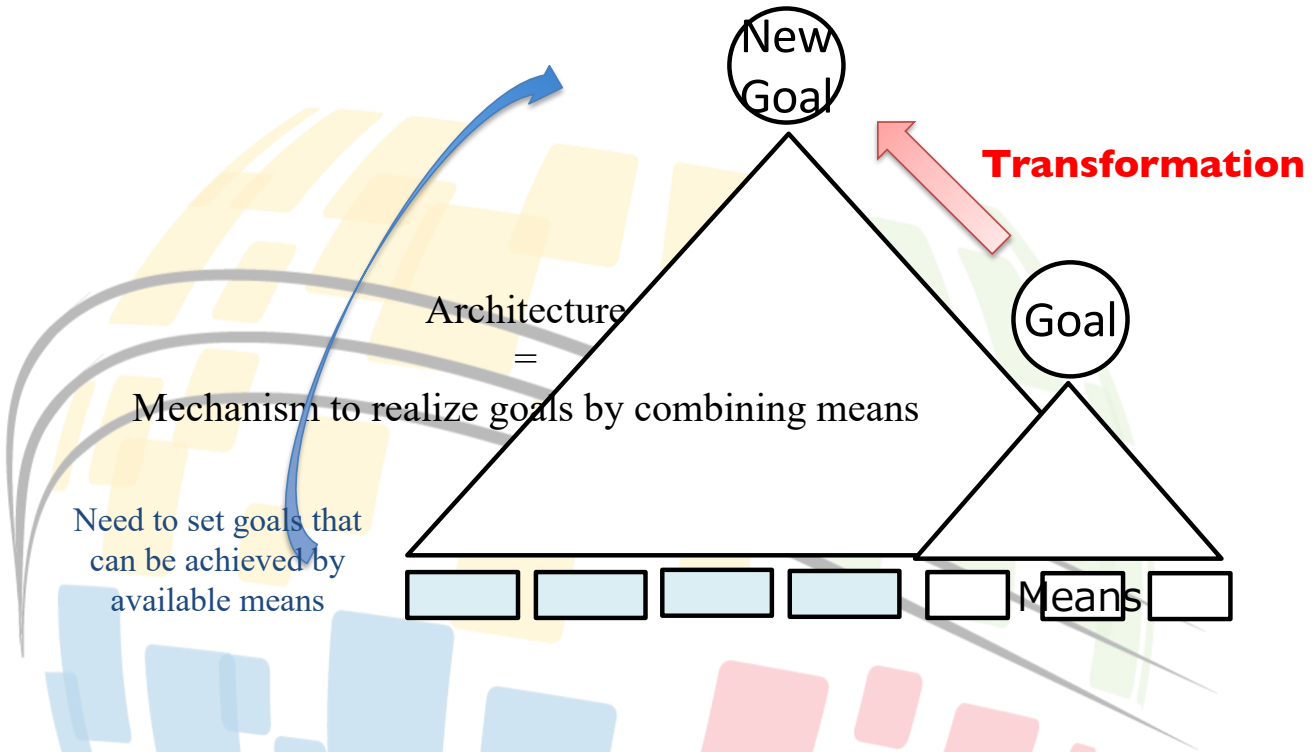


- The different features of appearance in finished products and nutritional components differed depending on the combination of different conditions were observed.
- For example, the different appearances observed in the cooking results of "Fuhafuha Tofu" were like **scrambled eggs** and **pancakes**.
- Near-infrared spectroscopy NIRS analysis showed that the **nutritional components** also differed due to the effects of cooking wear and tear caused by the different cooking processes.

(T Nonaka, et al., Systems engineering analysis for cooking recipes from the perspective of work instructions, APMS2021)

Case3: Tofu recipe in Edo period

Regenerate recipes that were not well understood based on recipes with insufficient information, including ambiguity



2. The replacement of existing ingredients and means
   + architecture design

Foodilization

Digitalization

Interpret and redesign the recipe, supplementing the parts that contain insufficient information where clear definitions of means and architecture cannot be confirmed

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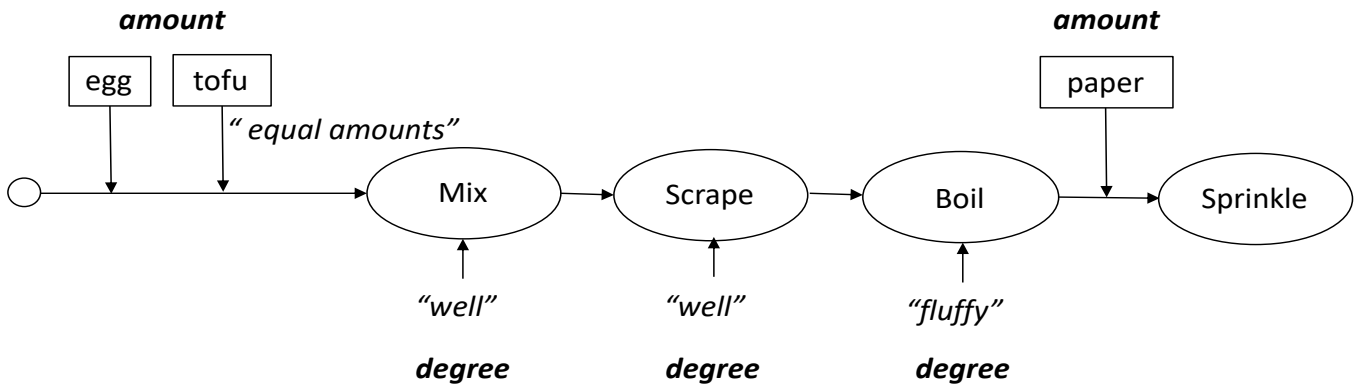
Regenerate recipes that were not well understood based on recipes with insufficient information, including ambiguity



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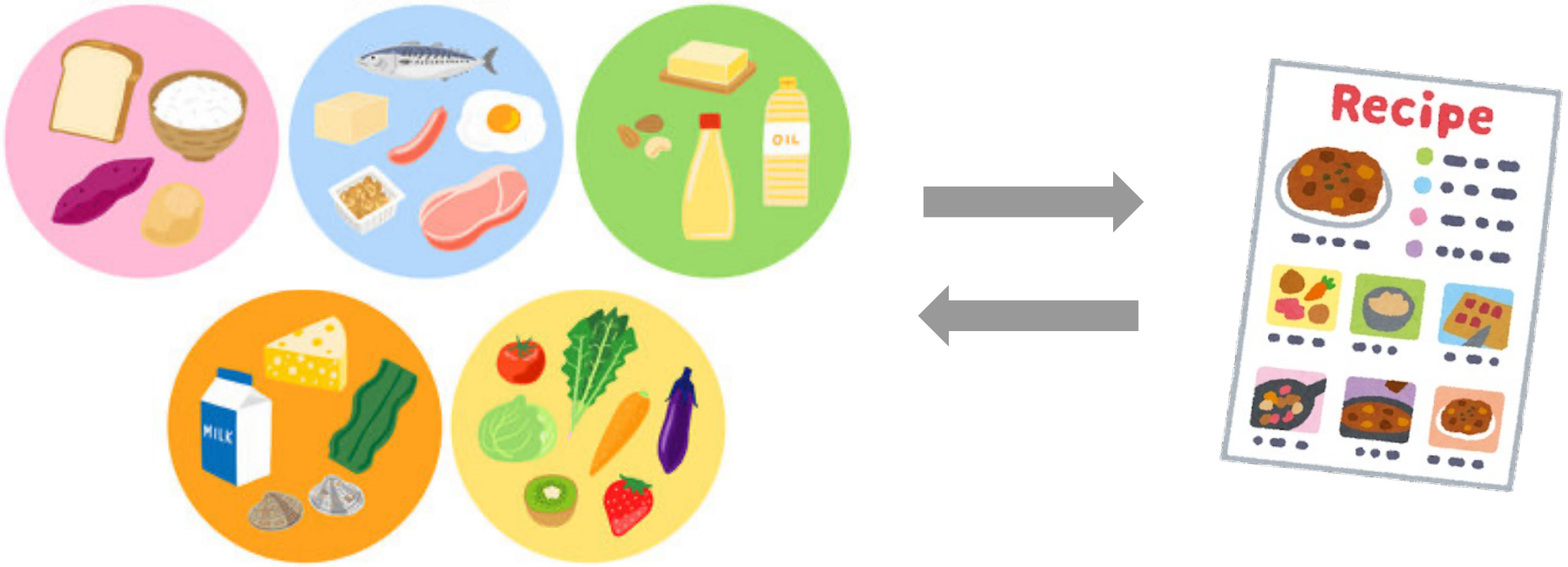
Recipe Design and Nutrient Adjustment



Recipe Design and Nutrient Adjustment

Calculate nutritional requirements by dividing by 3 meals per day

Recipe Design and Nutrient Adjustment

The required intake is covered on a daily or weekly basis according to the characteristics of the nutrients.

"-ilities"

- "-ilities" is a Related Discipline of Systems Engineering.
- It is called "Specialty Engineering.
- SEBOK Part6
  - Reliability, Availability, and Maintainability
  - Human Systems Integration
  - Safety Engineering
  - Security Engineering
  - System Assurance
  - Electromagnetic Interference/Electromagnetic Compatibility
  - Resilience Engineering
  - Manufacturability and Producibility
  - Affordability
  - Environmental Engineering

Source : Systems Engineering Body of Knowledge

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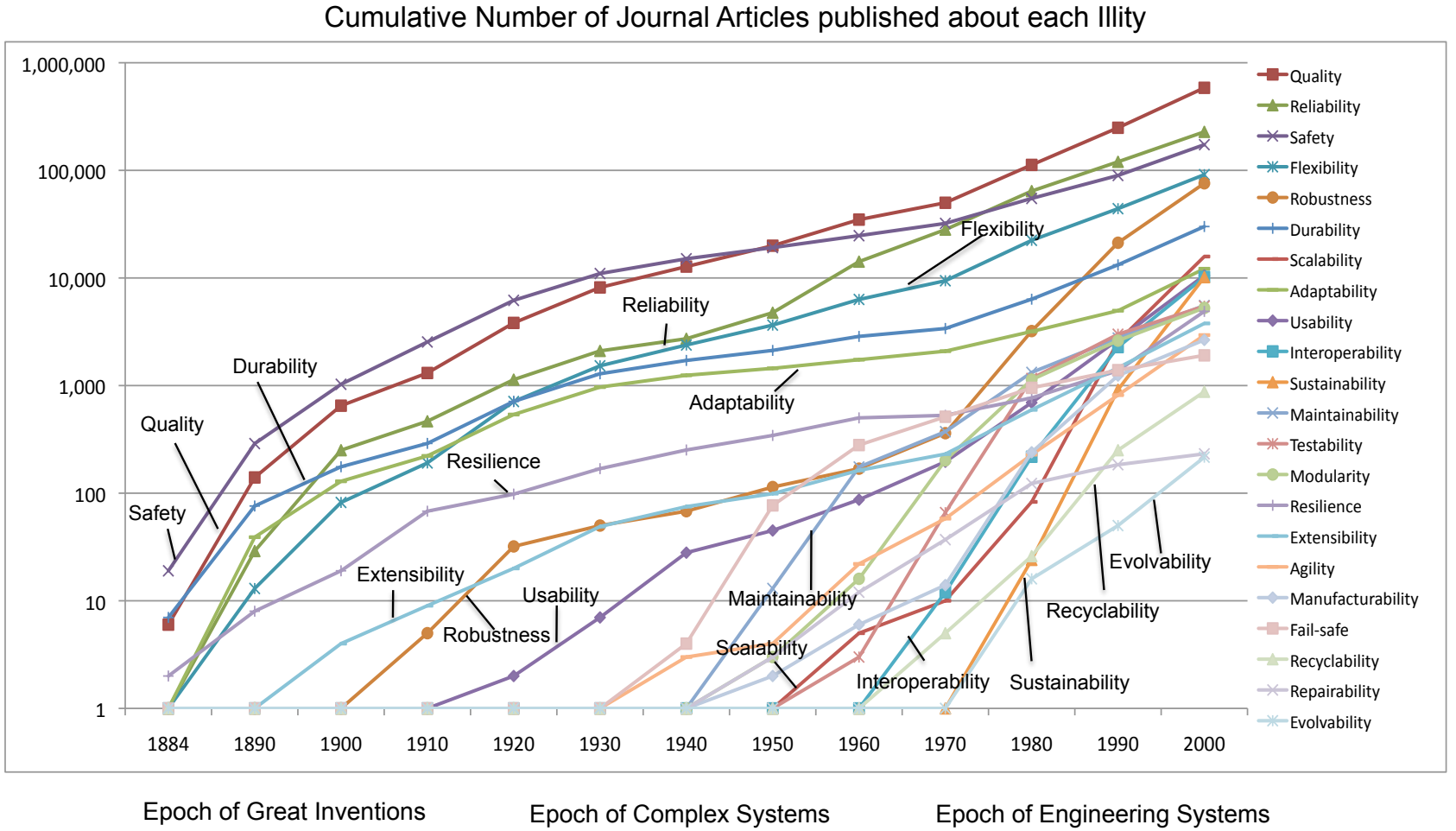
  - Resilience Engineering
  - Environmental Engineering

"-ilities" is a property that has to be viewed as a system “system characteristic” or “Lifecycle properties”

Source : Systems Engineering Body of Knowledge

"-ilities"



Source : Engineering Systems, MIT press

Discussions

The realization of a novel recipe design method, employing systems engineering techniques to delineate requirements from diverse perspectives and fundamentally redesigning the architecture,

with cooking methods and ingredients serving as the means to attain newly established objectives, holds the potential to not only create recipes that are more flexible but also significantly elevate their value-added attributes.

Conclusions

- This research proposed a cooking recipe design method concept using systems engineering to realize same characteristics of conventional dishes using meat using plant-based foods.

- In particular, we aimed to develop the method for FX (Food Transformation) in the context of value creation in DX (Digital Transformation).

- Establishing the approach presented in this presentation as a design method is a future challenge.

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hybrid event

Dublin, Ireland
July 2 - 6, 2024

www.incose.org/symp2024
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