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Review

Category-based food ordering processes

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The food industry presents an important area to apply new technology and automation. Especially, food ordering processes, that describe the transition of products' physical arrangement from disarray to a structural order, play a major role and will be considered in this paper. This kind of food processes will be extracted from other types of processes and clearly defined. Current ordering processes that have already been installed in the food industry are discussed. A categorisation system for classifying food products is presented. The key characteristics are 'Symmetry', 'Surface Condition', 'Hardness', 'Springiness' and 'Resistance to Damage'. This improved and novel food classification is unambiguous and it is able to interpret the foodstuffs categorisation table in an engineering approach. The overall purpose of food categorisation system is to link each category to a certain food ordering process. Having the mathematical algorithms that depend on the input disarray, the output array and the food product category appropriate and specialised equipment can be used to lead products into order. This can be described in a 3-dimensional matrix.

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Introduction

At many places in a food production process, previously well ordered products lose orientation and/or positional arrangement and need to be physically re-ordered for the next process. The goal of this study is to develop understanding to allow automation technology to accommodate this disorder.

The Food Standards Agency of the United Kingdom defines the food industry as "that from farming and food production, packaging and distribution, to retail and catering" (Food Standards Agency of the United Kingdom, 2009). As it accounts for 15% of the UK's total manufacturing sector by value, it is the largest sector of the industry. Within all areas of the food industry, automation has been applied in various ways to either support workers in their area of operation or function at a case-by-case basis. The motivations and drive forces for such automation are efficiency, consistency of quality, increased hygiene and reduced labour costs (Gray, 2001).

Whereas the motor industry has a robot for every 10 employees, the food industry has a robot installation per 1100 people (Reed, 2005). British Automation and Robot Association (2007) pointed out that robotics have started to make inroads in the food industry. It is expected that this sector will be the next big expansion area (Young, 2007). Though most robots in the food industry today are used for handling products packed in primary or secondary packing (Dai & Caldwell, 2009; Dubey & Dai, 2006; Yao & Dai, 2008) and palletizing, handling operations are of special interest where a large number of low-skilled personnel are used to transfer unpacked products or feed machines with little added value to the product (Wallin, 1997). In order to apply automation and robotics to the food industry, challenges have to be met. One issue is that food products are very diverse and display a wide range in size, texture, weight, susceptibility to damage, colour and shape (Pettersson, Davis, Gray, Dodd, & Ohlsson, 2010). Further, technology aimed at the food sector needs to be cleanable, lightweight, fast to cope with production rates and operate at typically low temperatures. Costa, Dekker, Beumer, Rombouts, and Jongen (2001) gives an overview of food classifications. The area of food processing has found use for technological classifications, namely in the improvement of operations' efficiency and effectiveness (Erzincanli & Sharp, 1997a, 1997b; Peri, 1990). Food products can be categorised in a matrix according to their

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characteristic traits. This is an important step to apply an ordering process to sort the products for handling. Erzincanli and Sharp (1997b) propose a method to classify food products into six categories: Shape, dimension, surface structure, compliance, temperature and weight. For each of these, 10 or more sub-categories are introduced. It can be seen that it is difficult to develop a universal ordering operation for such a wide range of product characteristics. Erzincanli and Sharp (1997b) mention that some food categories such as compliance need even more improvement. Their suggestions are to extend the classification by analysing elasticity, fragility, bruiseability, deformation etc. beside rigidity. Both, surfaces and compliance, have to be revised in a biological evaluation (Wurdemann, Aminzadeh, Dai, Purnell, & Reed, 2009). Further, food processing takes place at typically low temperatures close to freezing. At these conditions food physical behaviour is controlled by the required processing temperatures to preserve food safety and quality. In other words, changing the temperature means equivalently a change of the surface and compliance. Additionally, in the food industry food temperature is controlled for hygienic reasons. It is usually not possible to vary temperature for handling reasons. Consequently there is no need to categorise the temperature; it is more reasonable to keep rigidity and surface categories and improve these. However, it is important to know the geometrical profiles and characteristics. Other characteristics such as compliance, bruiseability and fragility need to be considered because food products with those characteristic will encrypt an ordering process for handling it. This is why an evaluation of textural characteristics has to be considered (Szczesniak, 2002). This classification is based on a fundamental rheoligical principle. Textural characteristics are defined and classified into mechanical and geometrical qualities. Though this is a basic concept only, textural features that influence the way of handling certain products can be useful. In 1994, Barbiroli and Mazzaracchio (Barbiroli & Mazzaracchio, 1994) propose a new method of classification of bakery products and flour confectionary. It takes into consideration parameters such as scale of product, basic typology, dimension, formulation, as well as flour, pastry, consistency and ingredients. However, this categorisation has a prevailing methodological purpose.

Pettersson *et al*. (2010) mentions that natural food products are often variable in shape and easily bruised. In the paper, a novel robot gripper is presented that utilizes the effects of a magnetorheological fluid and is able to handle a variety of shapes and sizes. Another innovative approach of a gripper for handling different shape categories is developed by Sam and Nefti (2010). This end-effector is also able to handle variable sizes, shapes and weights of unpacked foodstuffs.

In this paper the necessity of food categorisation will be illustrated in detail and a logical way of dividing different food groups will be presented. These complex constraints must be considered simultaneously for realistic solutions to be found and thus an interactive, multi-disciplinary approach is required. Section 'Categorisation of food products' of this paper will illustrate a novel food categorisation system for describing handling behaviours and explain the different characteristics that need to be distinguished. Ordering processes are only a subgroup of food processes. These are defined in section 'Classification of dispersed states and ordering processes'. The following sections 'Spatial ordering operations and Planar ordering operations' introduce food ordering operations that are commonly used in food industry. Section 'Relation between food categories and ordering processes' describes the relationship between the food categories and food ordering processes. The key facts of this paper are summarised in 'Conclusions'.

Categorisation of food products

In revisiting the product classifications of Erzincanli and Sharp (1997b), the authors consider the parameters 'Symmetry', 'Surface Condition' and 'Compliance' (where 'Compliance' comprises sub-divisions of 'Product Hardness', 'Springiness' and 'Resistance to Damage') to be more pertinent to robotic handling.

Symmetry

Categorising the shape of food products can be very problematic due to wide variation within one type of product. On the other hand many different products could be categorised similarly when the processing system for them is the same e.g., all the planar products (products with one dimension significantly smaller than the others) can be handled in a similar way assuming their other parameters do not vary. Food products have been categorised into four major groups: 'planar', 'ellipsoid', 'cylindrical' and 'complex structure'.

In order to maximise the efficiency of categorisation a product 'Symmetry' approach has been utilized. Here, symmetry should not be understood in an absolute geometrical way but with a tolerance of several percentage points to allow for natural products. In the 'Symmetry' approach, instead of the shape of the product, only the number of planes of symmetry and their relationship is considered. Taking account of the symmetry has another benefit of providing information about the 'Centre of Gravity' (CoG) of a product. Such information is useful for further processes including gripping, etc. If a product is of uniform density, the intersection of these planes of symmetry locates the CoG. On the other hand, the intersection of two or more planes of symmetry forms a line. In this case the CoG is described by the symmetry line.

Table 2 shows a summary of the relationship between the symmetry of the product and the shapes introduced in Table 1. It should be noted that the shapes are being represented with the codes generated by Table 1 e.g., a full ellipsoid with features is 'BB' or 'AAC' is a planar polygon.

Table 1. Categorisation of shape

A	planar	A	polygon	A	triangular
				B	rectangular
				C	polygon
		B	curvy		
		C	without distinct edge or corners		
B	ellipsoid	A	half ellipsoid		
		B	full ellipsoid with features		
		C	full ellipsoid without distinct features		
C	cylindrical	A	simple cylindrical		
		B	curvy cylindrical		
D	complex structure	A	consist of a set of simpler structures		
		B	intrinsically complex structure		

In Table 2, the first column represents the number of planes of the symmetry. The ∞ symbol in the last two rows of the first column expresses the infinite number of planes of symmetry. The second column shows the relation between the planes of symmetry, the third and fourth column state the axes of symmetry and their relation with the planes of symmetry, and the fifth column gives the code of the related shape based on Table 1.

Surface condition

Table 3 ('Surface' column) summarises the different surface conditions utilized in this paper. As it can be seen in some of the cases the table has been simplified in comparison to Erzincanli and Sharp (1997a, 1997b). This will reduce the number of elements in the final matrix indicating the way of processing the food products does not differ between the two groups.

Compliance

One of the main flaws of the previous literature is the fact that 'Compliance' has only been defined very loose. Szczesniak (1963) has given good definitions and qualitative measurements for 'Hardness' and 'Springiness' which has been used in this paper. However, there is no measure how fragile the product is. In this paper, in addition to 'Hardness' and 'Springiness' a new category has been introduced which measures how difficult it is to damage the product. This category is called 'Resistance to Damage' (a simplified version is shown in Table 3). The definition of 'Resistance to Damage' is as follows: If σ (measured in Pascal [Pa]) is the minimum stress required to hold the product what happens if a stress 2σ is applied to the product. Based on the result of such experience four categories have been defined:

- Crushable: The product is crushed under such a stress.
- Bruisable: The product is not crushed however it is damaged beyond acceptable levels and cannot be sold.
- Sensitive shell: The product is not bruised by the stress; yet a small surface damage to the product occurs, that expands over time and reduces its value.
- Hard to damage: Product is robust under 2σ stresses.

Categorising a basket of food products

Table 3 shows the complete food classification system. It can be seen that the total number of different categories of food products is 17,280. In comparison to previous literature it can be seen that the number of the categories is far less than the categorisation of Erzincanli and Sharp (1997a, 1997b) which has 2,359,296 categories. It can be argued that the process utilized for some of the categories especially for close hardness categories is not different; e.g., 'very soft', 'soft' and 'slightly soft' categories can utilize the same process with minor modifications. Therefore, the 'Hardness' category can be modified into three different categories of 'soft' (consisting 'little soft', 'soft' and 'slightly soft'), 'firm' ('little firm', 'firm' and 'very firm') and 'hard' ('slightly hard', 'hard' and 'very hard'). Similar simplification can be done for 'Springiness' which can be divided into three categories of 'plastic', 'springy' and 'extremely springy'. Also 'furry' ('Surface' category) is not a common product and, even if presented, it still can be handled with processes required for dry, not smooth products. Utilizing these considerations the total number of products decreases to 3168, which is a more acceptable value, keeping in mind that it is supposed to cover the whole range of food products.

Based on this categorisation a discrete chain code can be assigned to every food product. In this code each letter is independent. As Fig. 1 shows, every box represents and describes a characteristic feature of the food product. To make the categorisation clearer, here is one example: A tomato

Table 2. Relation between shape and symmetry

No. of planes	Relation betw. planes	Axis	Axis and the planes	Shape	Example
1	–	–	–	A or E	whole chicken
2	perpendicular to each other	1	Intersection of two plane	BA	baguette
3	mutually perpendicular	3	Intersection of each two plane	AA	biscuit
4	one perpendicular to others	4	Intersection of each two plane	AA	sambosa
5	one perpendicular to four others	5	Intersection of each two plane	AA	
∞	one perpendicular to others	1	Intersection of the remaining planes	BB, BC or AB	sausage
∞		∞	Intersection of each two plane	spherical	melon
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Table 3. Table of food categorisation

Symmetry		Surface				Hardness		Springiness		Resistance to damage	
A	1 plane	A	dry	A	smooth	A	very soft	A	non-elastic/plastic	A	crushable
				B	not smooth						
				C	furry						
				D	coated						
				E	air permeable						
B	2 plane	B	slippery	A	smooth	B	soft	B	slightly springy	B	bruisable
				B	not smooth						
				C	air permeable						
C	3 planes	C	Adhesive (sticky)	A	smooth	C	slightly soft	C	springy	C	sensitive shell
				B	not smooth						
				C	air permeable						
				D	coated						
D	4 planes					D	little firm	D	quite springy	D	hard to damage
E	5 planes					E	firm	E	extremely springy		
F	∞ planes, 1 axis					F	very firm				
G	∞ planes and axis, planar					G	slightly hard				
H	∞ planes and axis					H	hard				
I	no planes					I	very hard				

has infinite planes of symmetry and one axis of symmetry. Therefore its shape is in the 'F' category. A tomato surface is neither slippery nor adhesive; it is in the 'dry' category. It is slightly soft ('C' category of 'Hardness'), slightly springy, which fits in the 'B' category of 'Springiness', and bruisable. As a result, the code for a tomato is F/AA/C/B/B. Similar products in this category are peach and plum, for instance.

Classification of dispersed states and ordering processes

The food processing industry (Foodprocessing-Technology.com, 2009) defines food processing as a treatment of food substance in such a manner as to change its properties with a view to preserving it, improving its quality or making it functionally more useful. The range of food processing concentrates on food ordering, spreading, refilling, packaging, sorting, separating processes and many more: Spreading is e.g. used if crumbed meat pieces get flash frozen after frying. The idea is to achieve one layer of meat and a small space between each other in order to avoid pieces sticking together. An identical spreading process can be used for very different products such as for chocolate bars on entry of an enrobing machine. However, ordering covers many more processes. The position of food products have to be changed and brought into new orientation, structures have to be assembled; food items have to be in the same position to each other, so that it will be simple to package or process further.

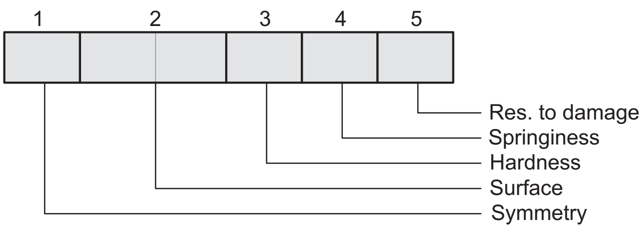

Fig. 1. Polycode for food categorisation.

In order to transfer foodstuffs from disarray to array certain steps need to be followed: As mentioned, a clear initial process categorisation is the most important part of the procedure. Here, the variation of food products, even within the same food type, complicates the classification as well as the practical difficulties of not damaging. This problem has been solved by designing a proper classification. As the classified products move on to the next step, different kind of sensors (high-speed cameras, colour sensors etc.) detect the position and orientation, in other words the disarray. In part 3 the disarray is translated into order. The added complication consists of mechanical properties of the handled components and selecting suitable end-effectors or automation machines. The applied equipment also needs to be up to hygienic standards. Finally, the food products have a structure (part 4) that can be recognised easily by machines again.

So, a food ordering process is a continuous action, operation, or series of changes taking place in a definite manner. This definite manner can be described as handling by systematically organizing food products. The preparation, again, is modified by an artificial process. Finally the author's definition for a food ordering process is as follows:

Food Ordering Processes are logical and/or comprehensible arrangements of food substances by handling, ordering or physically arranging it with a view to enhancing food processing operations i.e. preserving it, improving its quality, making it functionally more useful or packaging it.

In the food industry, there is a large number of food ordering processes. The majority of these are performed manually, although some food ordering machines are in use. The reasons why especially food companies hesitate to install new automation are based on the following facts: Types of food products often change and are taken out of the companies' range, so that the machines that process the food become redundant. Some food categories are complicated to handle, so that human beings have advantages by making use of their eyes and hands to arrange products of complicated shapes and no symmetry. A machine can be too slow and not reliable in this case; human beings need to be employed to supervise the automation line to add inspection and recovery facility. All the technology will either be profitable after a long term only or not at all.

Some existing technologies, operating in food ordering processing, are explained in the next section. Each type of ordering equipment is suited to different product categories. Some food ordering processes can deal with more than one food categories. Multi-head weighers can be used for a wide range of food products; the only limitation is the category 'Resistance to Damage'. On the contrary, buffering and guide tracks are in fact unlimited according to symmetries but can only handle dry or slippery food products.

Spatial ordering operations

Various shaped product distribution

Multi-head weighers are used for the accurate measuring of pack weight from a range of product weights. There is a range of bags which can be filled. On the one hand there can be large catering packs of many kilogrammes and on the other hand small bags of crisps or vegetables which can be handled at high speed and efficiency. Product packs containing several different components can also be mixed on a multi-head weigher.

A multi-head weigher consists of three main parts: a dispersion or feeder system, pool hoppers and a discharge chute that ends in a bag maker. The product is fed to the top of the multi-head weigher where the dispersion/feeder system passes it to the pool hoppers. Each pool hopper drops the product down into a weigh hopper beneath it as soon as the weigh hopper is empty. The weight of product in each individual weigh hopper is determined and a combination of hoppers is identified to get as close to the target weight as possible. The multi-head weigher opens all the hoppers of this combination and the product falls via the discharge chute into a bag maker or, alternatively, into a distribution system which places the product, for example, into trays.

The food products that can be handled by a multi-head weigher are mass products that do not have to have a certain shape. The surface condition is generally not important; the food industry processes pasta (F/AA/H/A/D), rice noodles (F/CB/C/B/D), shredded lettuces (I/BB/F/A/B) or even chicken legs (F/AB/E/C/D) with multi-head weighers. 'Hardness' and 'Springiness' do not need to be considered as well. The only crucial question is if the product will be able to be damaged easily. Since the product will be dropped three times at least, it should be hard to damage.

This type of a machine makes sense to be installed if the orientation of the product is irrelevant and the main purpose of ordering is to have the same amount of weight or the same number of products in one bag or tray.

Size grading

Many products are ordered (graded) by size. Normally, all size graders are designed to classify products by diameter or width. However, graders for classification by lengths are also available. All these graders use elements like screen mesh, perforated belt, plain rollers, taper rollers, diverging space, traveling chains, rotating rollers, vibratory trays etc., for separating fruits and vegetables to suit size and shape.

A size grader works on the principle of expanding gap rollers, for instance. The main chain has a series of rollers on fixed spacing, with another series of rollers mounted a little higher between them. At the feed end of the machine, the rollers are close together. As they move along, the top roller is raised at several adjustable points along the machine, creating a larger gap between it and the rollers below. This design allows for great versatility in determining where each size of product falls. The sizing can be adjusted to suit the volume of each size being graded out. Another way of size grader operates as follows: Having a perforated belt, which vibrates to move the products forward, food of the right shape and diameter falls through the belt into containers.

This type of ordering machines is ideal for carrots, Potatoes, Parsnips, Onions, Pickles, Apples and much more. As it can been seen, the symmetry is not important and the food products should be not sticking to each other. According to the categorisation table soft products should not be ordered by size graders.

Vibratory separation and re-orientation

The vibratory bowl feeder (Silversides, Dai, & Seneviratne, 2005) is a technique to translate three-dimensional disarray to one-dimensional structure and is used in cosmetics, pharmaceutical, electronics, metal and food working industries. This type of ordering machines consists of a bowl top containing the food products, that are randomly arranged, with a spiral track inside the bowl. The drive unit that can be electromagnetic and pneumatic drives, vibrates the bowl feeder, forcing the parts to move up a circular, inclined track. The track is designed to sort and orient the parts in consistent, repeatable positions. Suitable for bowl feeders are various kinds of rigid food products. They should be non-sticky, so that the products are singulated by the vibrations and move up the track piece by piece.

Planar ordering operations

Product transfer

A delta robot (ABB Limited, 2009) has been designed for high-speed pick and place tasks that is capable of around 150 picks per minute. This type of robot has typically a 1–2 kg payload. The key concept of the delta robot is the use of parallelograms which parallelograms restrict the movement of the end platform to pure translation (only movement in the x, y or z direction). The robot's base is mounted above the workspace to reduce factory footprint. From the base, three middle jointed lightweight composite arms extend. The ends of the three arms are connected to a small triangular platform. From the base, a fourth arm extends to the middle of the triangular platform to give the end-effector a fourth, rotational degree of freedom. Furthermore, Fanuc Robotics Ltd. has been developing a new generation of delta robots that has two rotational degrees of freedom in the end-effector.

The end-effector of the robot depends on the food product. Three end-effectors are common in food industry: The most used is the pinch gripper tool. It comprises a jaw-type device which exert pressing forces on at least two opposing elements of the product. The product is held by frictional forces. The vacuum device is almost as common. This consists of vacuum cups that seal against the product and grip is effected by differential pressure between inside the cup and atmosphere. The Bernoulli gripper (Erzincanli, Sharp, & Erhal, 1998) uses the Bernoulli effect of lowered pressure of a high velocity fluid to hold the product to the gripper. There is a huge variety of end-effectors.

The pick and place system is typically fed by conveyor belts. A vision system will determine the position and orientation of the food product. The robot picks the product up from the conveyor using one of the end-effector systems, bring the product into the desired orientation, and place it on the target location. The food categories that can be handled with a delta robot depends on the type of gripper that is used to move and re-arrange the food products. In general, all food products can be handled by the pick and place option. Sometimes this option is not the best solution and it is more economic to choose another food ordering process.

Buffering and guiding tasks

This type of ordering process is a very simple way of arranging physical order from disarray. In the food industry, sometimes products move from one conveyor belt to another in order to cool the food down by using different conveyor textures, for instance. By doing so, the products loose their constant distance to each other in x- and y-direction. Using a buffer that stops the individual products on the conveyor in periodical intervals for a short time, they will be re-arranged according to their distance to each other along the conveyor. If there are a few lanes of the same food product on the conveyor and the distance between the products perpendicular to the belt velocity is concerned, it is common to guide along tracks. In industry, there are several combinations of buffering and guidance tracks. Often, the tool that stops the food product in intervals has a similar shape as the product. So, the food gets ordered in x- and y-direction.

This idea is used for planar food that is not sticky because it is possible that adhesive products will stick to

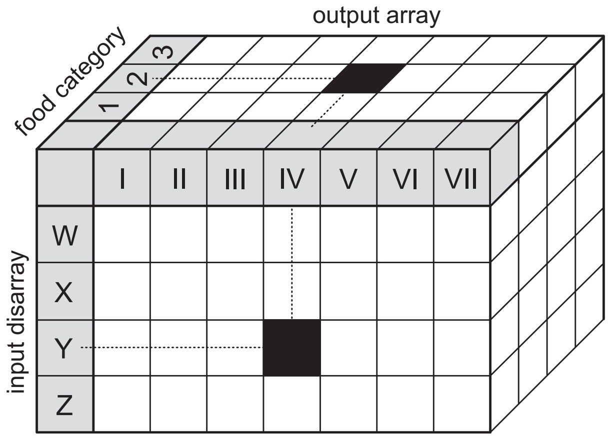

Fig. 2. 3-Dimensional matrix (Input, Output, Food Category).

a buffering tool. No attention needs to be paid to the other categories 'Hardness', 'Springiness' and 'Resistance to Damage'.

Relation between food categories and ordering processes

The previous sections have explained the importance of categorisation of food products and food ordering processes. As mentioned, the categories were defined to aid identification of appropriate handling and ordering processes. Having defined products and processes, they can be linked to define all possible food ordering operations. A 3-dimensional matrix (Fig. 2) illustrates the relationship between food products and ordering processes. Each food process can be described using the input (first dimension) and the output (second dimension) state. This can be demonstrated by the following example: A bakery company has deposited baked rolls randomly on a conveyor belt; they have lost their structured order and need to be re-aligned for packaging. Fact is that both, the initial unstructured and required structured arrangements, are given in the vertical and horizontal axes respectively. The third dimension represents the food category being processed, in this example breadrolls (B/AB/E/B/D). A useful technology could be the pick and place option considering the input, output and the food product. The end-effector can be a vacuum or pinch gripper. These two possibilities are typically used in food industry.

This 3D matrix approach gives a structure with each cell representing in generic terms a structuring process. Many food arranging methods already exist and these populate some of the matrix cells. Traversing along any of the orthogonal directions from populated cells indicates potentials for technology transfer of existing equipment, and unpopulated areas indicate areas for further research and developments.

Conclusions

A common approach when developing new applications for handling foods is to use previous experience of automation for similar foodstuffs. Whilst experience of this empirical experience is acceptable for a piecemeal approach, a more structured approach is developed in this review paper discussing novel and comprehensive systems to describe food ordering processes and products. The key development is an explicit way of classifying products, so that there is no discussion about the allocation to a certain group. The product description characteristics were chosen according to the needs of processing the different kind of products. Parameters such as temperatures were excluded because the temperature cannot be changed and if the temperature changes, the consistency of the food product will be different which means the type of food ordering process falls into another category. On the other hand, a definition needed to be established that extracts food ordering processes from other types of food processes. By discussing common and used automation for ordering processes and by linking these to certain food categories, gaps can be identified. These gaps represent manual ordering processes, that exist, but have not been automated. The outcome of this paper is hoped to provide a theoretical basis and leading edge methodologies to underpin all physical structure creation tasks. The next step will be to challenge these processes and develop a automated process in order to close detected cells in the 3-dimensional matrix.

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