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Comprehensive Principles for Enhancing the Adhesive Bound Book Performances

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Abstract: In addition to satisfying a book binding criterion, the paperback should provide content moments. Its binding style must be adjusted to book purpose. In publishing long-runs production, the perfect (adhesive) binding style with flexible hotmelt provides optimal binding durability with reasonable book price. Paperback should appeal to everyone through its visual-tactile senses. Taking the required actions in binding quality realization keeps track of comprehensive knowledge on various standardized paper substates (EN643:G3) that need to be wisely joined to realize perfect binding technique practices effectively. Moreover, designer technological awareness gained by experience provides potentials to understanding binding ability principles. The conducted research gives specific answers regarding paper cohesive capacity impact on consistency changes of adhesive bound book. It was concluded that higher paper drape capacity leads to increase of single sheet paper tension. Inappropriate bound book constructing was achieved although the flexible adhesive was used.

Keywords: adhesive bound book; binding performances; binding strength; paper cohesiveness

1 INTRODUCTION

An adhesive bound book (Paperback) is performed by hotmelt gluing without previous sewing book block with thread. As usual, the single paper sheets are sticked onto a cardboard cover that bound together create a distinctive shape of a book block spine (Fig. 1). This adhesive or unsewn binding style is the most preferable contemporary publishing binding technique in which the different standardized grammage rank of printing papers are used. Moreover, the book format sizes with their volumes are always adjusted to technological bindery features [1].

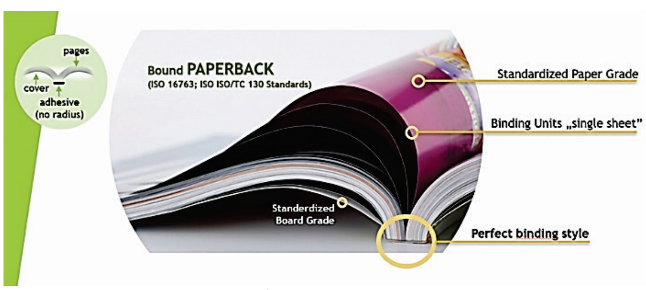

Figure 1 Perfect bound book construction

In addition, the perfect binding is specially dominated by hotmelt "one-shot" perfect binding technique in long-runs book manufacturing for various end-products (magazines, catalogues, brochures, class books, belles' letters, etc.). The reactive resin such as polyurethan is the most preferable hotmelt that is used with a standardized recycled and virginal paper stock. It is a flexible adhesive that provides initial bond strength by a chemical bonding paper substrate with resin. Therefore, the single paper sheets bond effectively with a paper cover. Bound together, they give desirable binding durability through a long period of time. This binding style is the most cost effective in a commercial book production.

Nowadays, the contemporary publishing perfect binding style provides productive manufacturing because of automated workflows with various hotmelts. The binding principles offer different variable procedures in which various bound book semi-products are produced. Thus, a bound book is built by the specific number of single paper sheets that are known as "the binding units" (Fig. 1). In addition, the signature is created by various printed sheet folding procedures. It presents a binding unit in a book block construction as well.

The signature volume is determined by a book design concept that must always correlate with a book format size. In addition, it is important that a book format size follows the paper series (A-C), and the chosen paper size classes (1-6) according to ISO 216:2007. A book designing concept needs to be led according to the standardized offset printing technologies, while a printing paper sheet format (0-4) must be adjusted to standardized perfect binding processes with limited end-product sizes [2].

As previously mentioned, the book engineering concepts need to be guided by comprehensive knowledge and practice skills on how to manage binding technologies properly [3]. If a graphic arts designer does not make a great effort to design a book concept, the bindery efficiency will fail. Hence, a bindery knowledge must be the imperative in book concept creations.

A binding unit might consist of a certain number of pages, from minimum of 4 pages, 8 pages, 12 pages, 16 pages, 32 pages to maximum 64 pages. The volume of a binding unit needs to correlate to the chosen standardized printing press format and the chosen standardized paper grammage rank. If chosen paper rank does not follow the book binding rules in the beginning, the binding efficiency will be significantly reduced. The bookbinder is led to ensure correct folding procedures which relate to various book format sizes (tall, lying, square and narrow).

The main rule utilization of standardized paper classes (1-6) including their certain series and sizes in relation to the used binding technologies. Accordingly, the designers must respect the folding rules and to know the usages of various folding sequence (right-angle folds, combination folds, parallel folds). The defined designing approaches significantly contribute maximum utilization of technological capacities in bindery sector. The important rule is to ensure the optimal number of binding units into a book block. So, the collected signatures with maximum constructed volume need to be put in order from the first to the last binding unit. Designer should achieve a bindery production with minimal semi-product loads.

In the perfect binding style, each signature into book block spine must be cut off before the gluing procedure [1, 4]. After cutting, the binding units "single paper sheets" construct a book block spine. Immediately after a book spine roughening procedure, the gluing block spine starts. The hotmelt is applied on the paper substrate. In most cases adhesion work is completed by resin bonding to the paper stock. The adhesion work intensity always depends on adhesive performance that appears at a moment of a book cover sticking onto the book block spine. By adhesive cooling, solidifying and moisture curing reactions more satisfying bond strength is reached. The bond line strength represents the binding strength capacity that is resistant to temperature and provides elastic resistance to pulling and flexing single pages out of a book block spine. Generally, reactive hotmelt resins provide excellent adhesion performances with various paper stocks and prevents block spine waving as well. Unfortunately, its high cost and particular properties make it unsuitable for widespread usages in bindery sector [5]. The standardized paper grades and adhesive usage (water emulsion, rigid hotmelt and flexible hotmelt) need to correlate with the book purpose, in which offered book designing concepts should reach the targets regarding economic, technological, and social aspects (Fig. 2).

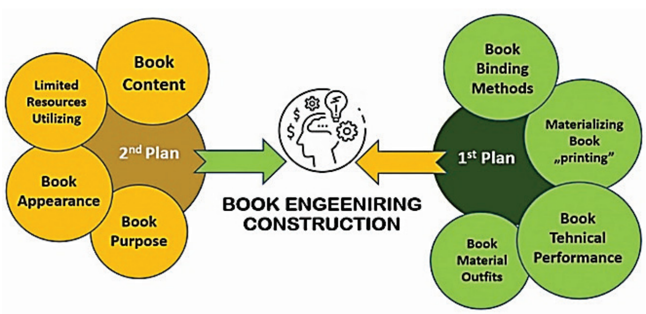

Figure 2 Book binding construction principles

It means to design procedures in prepress, printing and bindery departments effectively. By optimizing resource usage, the generated technological waste is reduced through a great number of binding procedures. Bindery efficiency copes with technological inappropriate book designing concepts (Fig. 2). Unfortunately, most designers haven't got technological knowledge and practice experience to predict the binding technology limitations. Correspondingly, the standardized paper grade choices (EN643:2001 Group 3) in book designing should be followed up through the standardized binding procedures (ISO 16763:2016 and Framework for ISO/TC 130 Standards-Graphic technology: 2019). Besides, paper binding capacities are sometimes not able to meet the technological expectations. Hence, the book designing constructions must lead to correct binding style solutions. In those situations, the designers should rely on respectable technological practices that lead to bindery efficiency [6]. Moreover, the goal of this research evaluates the engineering comprehension of bindery strategies (Fig. 2). The designers should implement them in their book designing concepts. Dr. Ralf Speth said, *"If you think good design is expensive, you should look at the cost of bad design"*. [7]. These performed research methodologies provide understandable principles of engineering solutions and technological practices in a perfect "one-shot adhesive" binding style, in which various standardized paper grade with various grammage were used.

1.1 Comprehending Paper Bound Capacity in Perfect Adhesive Binding Technique

A paper substrate refers to graphic arts material that is made primarily from plant virgin fibers and/or recycled ones. A paper sheet is an inhomogeneous material that is arranged in fiber layer networks which contain various pore sizes. Paper features directly refers to flat sheet that is made primarily from plant origin fibers, inorganic furnish and specific coatings. Moreover, fiber sources mostly define paper mechanical strength. Thus, the increase of chemical fibers in the paper lead to higher density and lower thickness in the paper sheet. In addition, specific standardized paper printing properties are achieved in a papermaking process. The various paper grades (EN643:2001) with specific physical properties in different printing techniques are produced in controlled standardized conditions. The properties vary and depend on amount of added inorganic pigments and fillers, chemical compounds, and sizing agents in the paper sheet. These ingredients directly affect paper sheet printing and adhesive perfect binding performances. Thus, paper grammage rises with higher amount of coating and higher quantities of fiber network layers in a paper sheet. A paper grammage and its tensile and folding strength are the most important properties in performing an optimal adhesive "one-shot" perfect binding style. Above all, the engineered designing bound book concepts always support standardized printing paper grades such as wood-free, wood-contained (less 10%) and recycled ones [8]. In addition, the virgin and/or recycled fibers together create fibrous structure of standardized printing coated paper whose surface must be treated with reactive hotmelt. For that reason, in automatic workflow that includes bound book publishing production, it is obligatory to use a flexible reactive PUR hotmelt that is more expensive than non-reactive EVA hotmelts and environment-unfriendly as well.

Standardized coated paper grades have a complex-built structure. Because of that reactive hotmelt is an excellent choice to ensure the binding capacity for various standardized paper grammages. It is well-known that high grade coated printing papers consist a few layers of coating that have a significant effect on bound book appearance [9-13]. Therefore, the flexible PUR hotmelt is an excellent choice in improving a book durability. Moreover, these standardized coated layers on a paper sheet, must at the same time provide efficient multicolour printing and preferable book appearance.

In addition, by higher fillers loading into paper sheet, its mechanical strength (tensile and tear) and stiffness decrease. Moreover, a standardized coated paper mainly leads to the segregation of fillers from the top surface of paper sheet. Consequently, the separated inorganic particles directly create the dust on the paper surface. The accumulation of the dust is the largest immediately after cutting off the spine edges (roughening procedure) in perfect adhesive binding workflow production [8, 14].

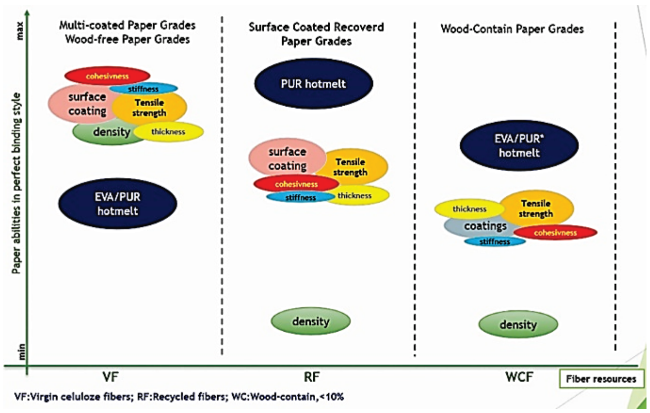

Figure 3 Various paper grades binding capacity by Perfect binding style

From previously mentioned, the standardized paper sheet stiffness relates to its compression or extension tensile strength, when a single paper sheet tends to resist an elastic deformation. In such circumstances, its stiffness increases with a higher fiber layers network which causes the higher bonding degree within the paper sheet.

In bookbinding the stiffness presents paper cohesive attributes. These attributes relate to paper toughness and its abilities to bend and drape well. The attribute "paper sheet draping well" is crucial in a bound book (Paperback) construction. Moreover, the paper binding capacity mainly correlates with standardized physical paper grades properties (Fig. 3). The critical point of view of each bookbinder is cohesive attributes of papers which need to provide controlled book opening and page scrolling at the same time. Perfect (adhesive) binding style efficiency directly depends on chosen and used standardized paper grade including their various grammage.

The efficient binding work quality is visible through reducing paper sheet tension that is located on the bond line of a book spine. Increasing paper cohesive attributes lead to its reduced bending, under which circumstances book pages haven't got ability to drape well under loads. It explains a higher possessed energy of each single paper sheet in book. Paper cohesive attributes may be revealed through their physical properties such as thickness and tensile strength. Both lead to tension increase on a book spine. Moreover, the increasing paper tensile strength always correlates with a higher quantity of virginal blanched beaten fibers. Paper sheet strength properties are increase with the higher number of fiber network layers [15]. Therefore, the virginal fiber network structures are a major contributor to providing paper cohesive attributes and they reduce paper stretching capacity as well [16].

In addition, the large share of recycled or wood contained fibers which are added to virginal ones [17] give the paper specific cohesive attributes. These paper grades show less tension on the bond line, but book page scrolling remain difficult. So, its cohesive attributes must be adjusted to adhesive perfect book binding style. It means that each individual paper sheet participates in creating a balanced shape of a book spine. Another reason to improving balanced shape is to take a correct paper sheet grain direction. Book designing construction must be led by paper sheet grain direction (MD) that always aligns parallel with book spine (Fig. 4-B). So, the accent is to reduce paper cohesive attributes, and this is possible to achieve by paper cross-grain direction (CD) in a book block. In that loaded circumstance (compression or extension), a paper sheet remains permanently deformed but it still tends to return into previous position (Fig. 4-A).

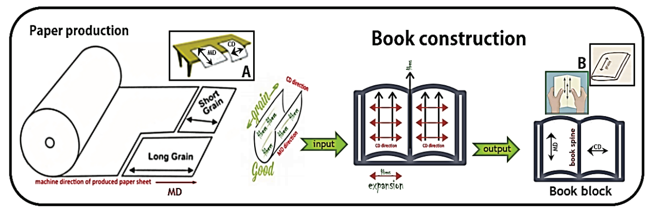

Figure 4 Book constructing and paper grain direction interrelation

1.2 Paper Drape Capacity

A bookbinder explains the term "paper draping" as a single paper sheet ability to fall easily in gutter margin. If a book page resists elastic deformation in a book spine it means that it doesn't drape well and its stiffness increases (Fig. 6). By higher paper drape capacity, the book pages tend to keep existing shape and resist falling naturally onto adjacent book pages. Determining the drape factor value and its higher result expresses higher paper rigidity because the book pages can't lay down easily. Therefore, book pages show tension that increase on the bond line and finally cause permanent book spine deformation. Moreover, a stiffer paper shows the resistance towards compression and extension. Hence, the loads are transferred directly into a book spine although book pages try to stretch. The constant balanced book spine shape is the most important factor in performing correct book construction. So, the obligation of each designer is to make judgement about paper drape capacity. It must be based on making book prototype by consulting a bookbinder long before starting bound book production. Another important factor for balancing book spine shape is paper sheet anisotropic behaviour. So, the arranged fiber network layers directly affect paper drape capacity. It means that its structural characteristics (fiber resource types, papermaking process types, intensity of fiber network connectivity, paper thickness, paper density, paper porosity, and paper consistency) significantly influence determined drape factor value. Moreover, other factors such as inorganic components and other chemical compounds [16] additionally contribute to paper cohesive attributes, which are responsible for preferable appearance of book construction.

The binding paper stiffness is a very important factor for a bookbinder [16]. If a designer takes inappropriate paper binding stiffness, problems occur that cause poor appearance and handling having difficulty in the bound book. Thus, understanding the term "paper drape capacity" leads to novel approaches on how to improve bound book functionality. In addition, the designers should perform comprehensive approaches to explain paper cohesive attributes. Nowadays, bookbinders confirm that many designers have no practical competence to offer functional and efficient bound book concepts. Unfortunately, the designers' policy is mainly focused on putting the correct paper grain direction of paper and book format size changes.

1.3 Evaluative Comprehension of Book Spine Control

Term drapability relates to the paper drape factor value. By reducing drape value, a paper sheet is capable falling naturally onto a gutter margin of an opened book as shown in Figure 4-A. Paper drapability is significantly lower through its cross-grain direction (CD). Therefore, the designers should choose the optimal paper cohesive attributes which will compensate stress on a bond line. This is the first step in making the best condition to bound book appearance during its handling (Fig. 4-B). Moreover, if designers understand the paper cohesive attributes well, a bound book construction should lead to its preferable impression (Fig. 4). It means that readers don't need a greater effort to open the book entirely and it won't ultimately lead to deformed book spine shape.

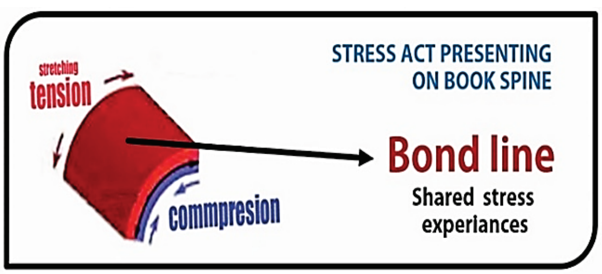

Figure 5 Existing stress shown on bond line

From previously mentioned, the term drapability refers to paper cohesive attributes that express potential paper energy. So different standardized paper grades with their various grammages give different potential energies which lead to various paper cohesive attributes. For that reason, the key practical element is the right choice of potential energy of paper which builds up the book pages. So, the spine shape book deformation is caused by an effect of increasing paper potential energy. Moreover, an adhesive flexible layer, which is formed on the bond line, needs to neutralise, and compensate stress that comes from single paper sheets inside of book block (Fig. 5). If the book pages the potential energy is too high, the pages are not able to move freely inside of block spine space. No doubt, inappropriately chosen paper cohesive attributes cause difficultly in book opening and scrolling. For that reason, comprehensive adhesive binding knowledge and practice skills together with standardized paper grades and their various grammages ensure a functional designed book concept. This approach ensure satisfaction to readers because they are able to keep the book opened effortlessly without spine deformation, from book head to tail (Fig. 5 and Fig. 11).

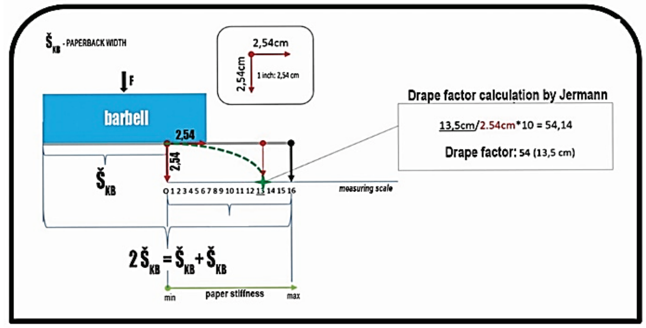

Figure 6 Drape factor measuring

In perfect (adhesive) binding, drape factor measuring (Fig. 6) is on a relative scale which is constructed by Pete Jermann [18]. A measured value relates to paper sheet stiffness, and it determines paper binder's possibilities. When drape number increases on a relative scale towards No.16, it means that it is stiff paper (Fig. 6). Moreover, whatever the drape number is potential paper energy always rises by reducing the book width ($Š_{KB}$) including different standardized paper grades and their various grammages. Potential paper energy falls with increasing of book formats as well.

Perfect (adhesive) binding technique, with reactive hotmelt, provides quite small radius of book opening. Hence, the apex arc is barely perceptible on a book spine. For that reason, paper cohesive attributes have a significant effect on the balanced book spine shape. So, the selected standardized paper grades and their specified grammage must drape well to avoid controlled opening of a book spine.

The designers must be aware that paper cohesive attributes generally lead to more tension on the bond line with hotmelt [19]. Moreover, its cohesiveness rises with inappropriate book format sizing. Hence, a compromising binding solution must involve favourable strength durability, practical usage, and desirable bound book appearance. As a rule, the designers should neglect present designing practices and start to engage in advanced solutions which rely on determined features of standardized paper grade properties. Primarily, a designer must be able to provide advanced designing concepts and to make great number of prototypes. The purpose of this approach certainly makes a preferable book construction that provides proper book spine stretching and returning to its initial shape.

1.4 Reflection on Paper Substrates Performance

Various standardized paper substrates must satisfy ink transfer conditions and perfect (adhesive) binding procedures as well. In multi-colour ink transferring, paper surface printable properties are improved with various finishing treatments like surface sizing or coating (Fig. 7). Various modified coated surfaces enhance internal paper resistance towards fibrous release (fibers and fines) and other inorganic resources (fillers and pigments) that cause making dust within perfect (adhesive) binding manufacturing. Moreover, these inhomogeneous resources lead to insufficient paper cohesive strength which is a special feature of lightweight paper grades [20].

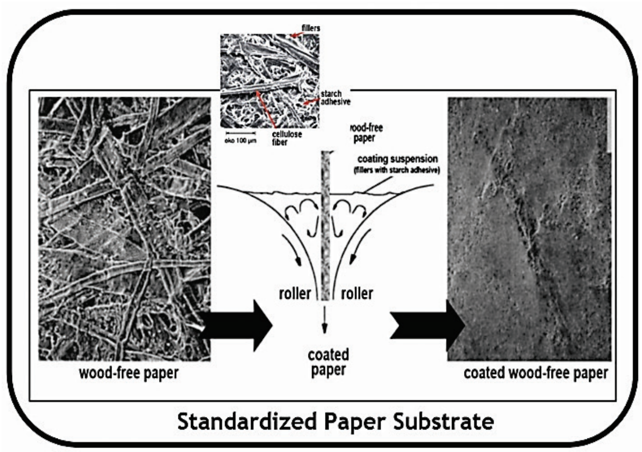

Figure 7 Paper substrates appearance

Standardized paper grades stability matches up with their structure (physical) properties that are achieved inside of papermaking procedures. Paper grades properties are tailored for end-use requirement, for printing sector exclusively. Standardized paper grades dimensions and their tensile strength are determined by fiber resources, inter-fibers bonding intensity and fiber arrangements during paper sheet formation. While the virgin cellulose fibers contribute to higher fiber networking, the lignin contained fibers and recycled one's cause lack of paper sheet formation. Such feature is characteristic for bulky and recycled standardized paper grades.

Flexible virgin that are mainly bleached are created in chemical pulp process. Tensile strength of standardized paper grades enhances because of inter-fibers connection. However, if the share of recycled fibers increases during fibers networking, it will finally lead to paper tensile strength reduction [21].

Standardized offset printing wood-free paper, with a significant low residual lignin content, is produced in various grammage. It is a high tensile strength paper that is made up of bleached fiber with the fine coated surface layers. In addition, book products (magazines, catalogues, books) preferring a variety of two-sided woodfree coated paper grades, while is the standardized art paper grades mostly suitable for illustrated books and brochures [22]. Moreover, high-quality magazines and catalogues for advertising, in long-runs adhesive perfect production, are always printed on standardized fine coated paper grades including double or triple surface coatings which is made up of a higher share of recycled fiber resources.

Nowadays, in papermaking production except virgin fibers are added recycled ones and the other components for achieving a preferable paper networking structure. Moreover, the various standardized paper grades contain different quantities of inorganic and organic compounds such as fillers, adhesives, pigments, binders, etc. [23]. Thus, fillers improve a standardized paper sheet formation by filling the voids between the fiber-networking. Fillers directly enhance a printable performances of standardized paper grades. In addition, the inorganic pigments that are added in surface coatings generally are mixed with a starch. The starch is an adhesive that acts as binder to compose a complete paper structure [24]. While the starch as adhesive enhancing paper compressive strength [16], by fillers overloading lead to reducing its compressive strength. At the same time, the fillers cause weaking inter-fiber bonds and to enhance a paper dimensional stability because of fillers humid resistance [26]. So, the standardized paper strength capacity rises because of flexible fiber network that are mostly made of fibrillated virgin fibers and small fibrils. Moreover, a higher paper potential energy is a mutual relationship with a its strength capacity. For instance, some bookbinder experts have practical skills for estimating paper cohesive attributes.

They precisely observe the paper sheet structure to estimate its bending stiffness that always connected with other paper ingredients which are provided a denser layered paper structure. These standardized paper grades always generate the dimensional stable paper sheets regardless of its grammage. They have higher bending stiffness performing about others with lower share of added ingredients.

In bookbinding, the main target is to choose the standardized paper grades and grammages that have higher density of surface layers and lower density of middle layers [16]. This is one verifiable approach to determining preferable cohesive attributes of standardized paper grades and their grammages that should lead to a preferable bound book constructing.

1.5 Comprehensive Approach to Bound Book Designing Concept

As a rule, the book designing concepts are based on correct binding capacities of standardized paper grades and their grammages (EN643:G3.01-3.19.). Paper cohesive capacity (stretching and compression) affects book spine appearance because of bond line loading. Paper cohesive attributes are shown at the moment opening and scrolling of book pages, when a minor apex arch is created on a flexible and mobile book spine. So, the apex arch appearance on the bond line can help designers with constructing bound book prototypes, which will lead to connecting current experiences and a prior comprehensive binding knowledge.

Creative cognitive visualization helps everyone to understand problems. Moreover, designers should make a few book prototypes and finally ask themselves "Which chosen standardized paper grade and its grammage give a minor apex arch on a book spine?" By answering that question, awareness about book designing concepts create new approaches and strategies on how to advance perfect (adhesive) binding technical and technological aspects in accordance with bookbinder recommendations.

It is obvious that designers should learn more. They must be able to explain a designing concept in more details to a bookbinder who produces an end-product in long-runs manufacturing and to use various technical-technological equipment inside machine processes. For that reason, designers must be superior in making decisions since they need to have background knowledge and technical practice in book making. Moreover, they should be aware of the significant differences between hand bookbinding (short-runs production) and edition bookbinding (middle-runs and long-runs production) features. In addition, designers must determine the importance of a book purpose long before it's end-producing. Therefore, they should come up with advanced approaches to interpret which binding forms and types are appropriate to the book content. Designers must move binding solutions forward with a reasonable meaningful manufacturing and economic efficiency as well. It is important to choose standardized paper grade and its grammage which will provide the book`s visual-tactile sense and its durability at the same time. Furthermore, designers should enhance their book designing approaches to improve bindery efficiency. The implementation of comprehensive practices in bookbinding concepts will lead to the increase in the number of satisfied end-users.

2 EXPERIMENTAL

The Perfect bound books (Paperbacks) process was performed by gluing the single paper sheets on standardized cardboard cover (trade name: Symbol Card 240 gm^{-2}) and they together create the bound book spine. The adhesive (unsewn) binding style was performed in full automated Horizon-470 perfect binding machine including book block and cover feeding, book block spine milling (roughening) and gluing sections, smoke extractor of hotmelt and delivery conveyor as well. The minimum book block size is 105×145 mm and the maximum book dimension that can be produced is 320×320 mm including the maximum book block thickness of 65 mm. The reactive PUR flexible adhesive was used for various grammages and various formats of books (tall and square). The chosen standardized paper grammages (gm^{-2}) refer to standardized paper basic weight that is determined by ISO Standard 536. The grammage term was used in representing the research results instead of the term basic weight. The evaluating procedures of book samples and standardized paper sheets were performed using standardized test methods and visual judgements.

2.1 Materials

2.1.1 Paper

In Paperback edition (publishing) manufacturing, various paper grammages of the same grade were used as listed in Tab. 1. Paper substrates belong to standardized high quality wood-free 2-side fine coated printing paper (EN 643, Group 3). It has 100% chemically pulped fiber furnishers with fillers and binders (starch and pigments) which lead to the increase the paper`s smoothness and strength [27].

Table 1 List of used paper grade with its various grammages

Trade Name	Grammage (gm^{-2})	Abbreviation
Garda Gloss	90	**90^{CP}**
Garda Gloss	115	**115^{CP}**
Garda Gloss	135	**135^{CP}**
Garda Gloss	150	**150^{CP}**
Garda Gloss	170	**170^{CP}**

2.1.2 Adhesive

The used reactive hotmelt adhesive (TECHNOMELT PUR 3317 BR known as PUMELT-QR 3317 BR) is reactive prepolymer polyurethan. According to material safety data sheet, it performs excellent adhesion (bond strength) to a various paper substrate. Final bond strength was achieved by physical curing process of the adhesive layer film on the paper substrate [28, 29].

3 MEASURING METHODS

3.1 Sample Preparation

A total of 250 Perfect-bound books were made (50 Paperbacks of each paper grammage) in order to determine the binding strength. Various grammages of identical unprinted paper grade were used in the perfect binding production samples.

Different Paperback formats (Tab. 2) included identical book spine width of 40 mm. The signatures as binding units in a book block were bound by using the perfect binding technique with standardized reactive polyurethan (PUR) hotmelt adhesive. Perfect bound book samples were manufactured under standardized conditions (ISO 16763; ISO 187; ISO/TC 130 Standards Framework).

Table 2 List of used Paperback samples

Book spine width (mm)	Format sizing (mm)	Abbreviation
40 (75 KS*)	B5-tall (160×240)	**$_{B5}90^{CP}$**
40 (75 KS*)	A5-tall (148×210)	**$_{A5}90^{CP}$**
40 (75 KS*)	Square 310×310	**$_{SQ}90^{CP}$**
40 (57 KS*)	B5-tall (160×240)	**$_{B5}115^{CP}$**
40 (57 KS*)	A5-tall (148×210)	**$_{A5}115^{CP}$**
40 (57 KS*)	Square 310×310	**$_{SQ}115^{CP}$**
40 (50 KS*)	B5-tall (160×240)	**$_{B5}135^{CP}$**
40 (50 KS*)	A5-tall (148×210)	**$_{A5}135^{CP}$**
40 (50 KS*)	Square 310×310	**$_{SQ}135^{CP}$**
40 (46 KS*)	B5-tall (160×240)	**$_{B5}150^{CP}$**
40 (46 KS*)	A5-tall (148×210)	**$_{A5}150^{CP}$**
40 (46 KS*)	Square 310×310	**$_{SQ}150^{CP}$**
40 (40 KS*)	B5-tall (160×240)	**$_{B5}170^{CP}$**
40 (40 KS*)	A5-tall (148×210)	**$_{A5}170^{CP}$**
40 (40 KS*)	Square 310×310	**$_{SQ}170^{CP}$**

The volume of a signature as a binding unit (KS*) consist of 16 pages.
The chosen paper grade class is 1 and the chosen paper format series is B. "B1 paper sheet"
The tall book formats were made by right angle folds, for the square book formats were made combination folds.

3.2 Determination of the Binding Strength

The binding strength is evaluated according to ISO 19594. It is evaluated by pulling out a single sheet from the book block and measuring the maximum force which is result of the page-pull procedure. Page-pull test was performed in standardized conditions (ISO 187), on IDM Page Pull Tester, Model P0011. The binding strength of the Perfect bound book samples is calculated according to ISO 19594:2017 and Eq. (1).

$$BS = \frac{F_{\max}}{l} \tag{1}$$

$F_{\max}$ - maximum force (N)
l - distance from book's head to tail (cm)

Table 3 Binding strength evaluation (ISO 19594)

Quality level of Binding Strength	Binding Strength (Ncm^{-1})
Very good durability	> 7.0
Good durability	≤ 7.0; > 6.1
Sufficient durability	≤ 6.1; > 5.1
Poor durability	≤ 5.1.

The quality levels for binding quality consistency are based on coefficient of variation (Tab. 4).

Table 4 Binding quality expresses to the consistency level (ISO 19594)

Quality level of Consistency	Variation Coefficient
Very good durability	< 0.10
Good durability	> 0.10; ≤ 0.15
Sufficient durability	> 0.15; ≤ 0.20
Poor durability	> 0.20.

3.3 Drape Factor Determining

Paper drape factor was performed in standardized conditions (ISO 187), which influences Perfect bound book opening behaviour (Fig. 6). It presents how capable the unglued paper sheet is to exert at the bond line [18]. After the measurement of the paper extension length which drops one inch at the leading edge, drape factor was evaluated according to Eq. (2).

$$Drape\ Factor = \frac{1}{2.54} \times 10 \tag{2}$$

4 RESULTS AND DISCUSSION

Each measuring method was performed ten times. The obtained descriptive results of mean (M), standard deviation (σ) and coefficient of variation (CV) were used as an aid in estimating paper bindability (one high-quality paper grade with its five different grammages). The sample dispersion values were used in the evaluation of the bound books opening behaviour. Cohesive paper attributes were represented in relation to the binding performance of a single paper sheet in a bound book.

4.1 Determining Binding Strength Quality and Its Consistency

The paperback samples, with their spine thickness of 40 mm, were tested at seven test positions (5%, 20%, 35%, 50%, 65%, 80% and 95% of the total number of pages). For the page-pull testing, 10 samples of each paper grammages and book format size were measured in 7 different test positions in accordance with the certain number of Paperback pages (1184 pages, 912 pages, 800 pages, 736 pages, 640 pages) as shown in Fig. 8. The obtained results of binding strength level quality and its consistency are presented in Fig. 9. The mean binding strength results refer to Perfect bound book durable permanence. Moreover, the variation coefficient (CV) results relate to stability of the bond line. The behaviour manner on how book pages hold together with adhesive is presented in this research.

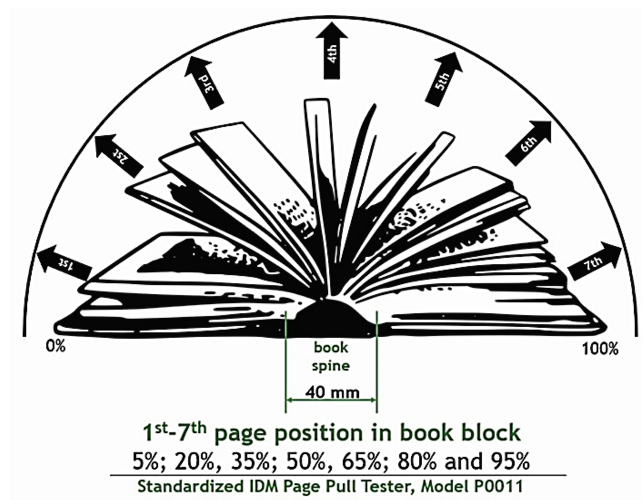

Figure 8 Positioned pages in Perfect bound book

The binding strength measuring was conducted by pulling pages from a book spine. The obtained results by pulling out 7 single paper sheets from a book block in total of five groups of B5 book formats ($_{B5}90^{CP}$, $_{B5}115^{CP}$, $_{B5}135^{CP}$, $_{B5}150^{CP}$and $_{B5}170^{CP}$) were classified as a very good book durability (>7.0 Ncm^{-1}) as shown Fig. 9. Moreover, B5 format Perfect bound book is the most represented in edition binding production and therefore it is presented in this research.

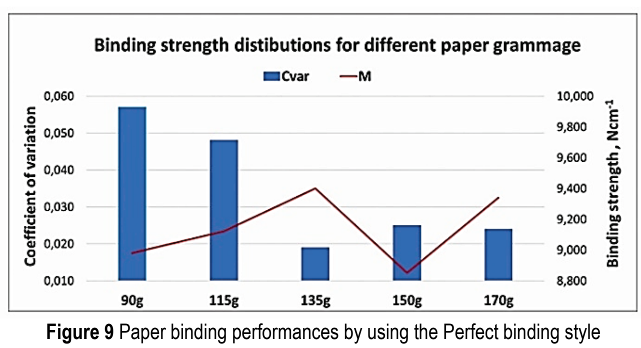

Figure 9 Paper binding performances by using the Perfect binding style

The excellent binding strength mean results were achieved respectively sample $_{B5}150^{CP}$ Paperback (> 8.51 to > 9.18 Ncm^{-1}), followed by $_{B5}90^{CP}$ Paperback (> 8.10 to > 9.68 Ncm^{-1}), $_{B5}115^{CP}$ Paperback (> 8.19 to > 9.50 Ncm^{-1}), $_{B5}170^{CP}$ Paperback (> 9.05 to > 9.69 Ncm^{-1}) and $_{B5}135^{CP}$ Paperback (> 9.11 to > 9.71 Ncm^{-1}). Considering the paper various grammages, the obtained order of results was expected because of PUR hotmelt elastic properties. Moreover, sample 90^{CP} 2-side fine coated printing paper is not 1st on the list although it showed very good drape performance (>11.42 to >12.2) as shown in Fig. 12. In addition, a very good durable performance was determined for all 7 test positions for five various grammages (90^{CP}, 115^{CP}, 135^{CP}, 150^{CP}, 170^{CP}) of the same paper grade. The obtained coefficient of variation (CV) results were achieved respectively $_{B5}90^{CP}$ with 1184 book pages (0.057 ≤ 0.10) followed by $_{B5}115^{CP}$ with 912 book pages (0.048 ≤ 0.10), $_{B5}150^{CP}$ with 736 book pages (0.025 ≤ 0.10), $_{B5}170^{CP}$ with 640 book pages (0.024 ≤ 0.10) and $_{B5}135^{CP}$ with 800 book pages (0.019 ≤ 0.10). The weakest consistency was noticed for sample $_{B5}90^{CP}$ with the largest number of book pages. The obtained CV results decrease, and they do not follow book page reductions (1184 pages > 912 pages > 800 pages > 736 pages > 640 pages). The bound book sample $_{B5}135^{CP}$ with 800 pages showed the best performances and maximum stability on the bond line (9.40 Ncm^{-1} and 0.019). The achieved performances are the result of the results derivate from a correct book construction and the efficient layered bound fiber network inside the paper sheet sample 135^{CP}. Moreover, the paper sheet structure is denser on its surface and central part. Therefore, its structure shows affinity for adherence and the increased binding capacity with hotmelts. In addition, the CV results of other samples are significantly higher than sample $_{B5}135^{CP}$ (0.019 ≤ 0.10). The CV results were achieved respectively $_{B5}90^{CP}$ (0.057 ≤ 0.10) is 3 times higher than $_{B5}135^{CP}$, followed by $_{B5}115^{CP}$ (0.048 ≤ 0.10) 2.5 times higher, $_{B5}150^{CP}$ (0.025 ≤ 0.10) 1.3 times higher and $_{B5}170^{CP}$ (0.024 ≤ 0.10) 1.26 times higher. It is noticed that by the decrease of CV results ($90^{CP} < 115^{CP} < 150^{CP} < 170^{CP}$) the paper grammage decreases as well. In accordance with paper grammage reduction, the fiber network layers density decrease [16]. On the other hand, sample paper cohesive capacity rises under loading respectively ($90^{CP} > 115^{CP} > 150^{CP} > 170^{CP}$) as shown in Fig. 9. From previously mentioned, paper sheet stability of sample 135^{CP} is additionally insured by surface layered coating which boosts its cohesive attributes as well. The increased CV results are caused by inappropriate paper structure which is located in the middle and on the top of the paper cross section (90^{CP} CV: 0.057 > 115^{C} CV: 0.048 > 150^{CP} CV: 0.025 > 170^{CP}CV: 0.024 > 135^{CP} CV: 0.019). In Figure 10, only the book sample $_{B5}135^{CP}$ showed stabile durability performances for all seven different book page positions.

The standardized paper-making machine is not able to entirely create a straight fiber layered networks inside the paper structure although they follow the machine direction [16]. Therefore, the aligned fibers of a paper sheet need to follow a book spine direction. It strictly means that the grain machine direction (MD) must be parallel with a book spine, from its head to tail (Fig. 11). Because of grain cross-machine direction (CD) a paper sheet has lower resistance to bending and it easily falls on a book cover. By reducing its bending stiffness, paper drape capacity increases. This is expressed by Jermann's a lower number of drape factor (*DF*<16) as shown in Fig. 6. In accordance with Jermann`s observation criteria on a relative scale [18], preferable construction of book can be created only with an optimal paper cohesiveness by which additional loads on a book spine are avoided (Fig. 5) in terms of using PUR flexible hotmelt which neutralizes loads on Paperback bound book spine, from head to tail as shown in Fig. 11.

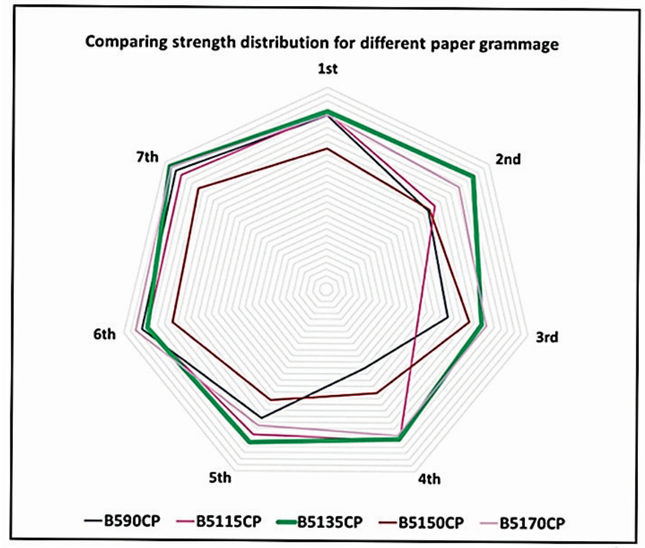

Figure 10 Permanence of Paperback sample $_{B5}135^{CP}$ on seven different page-pulling positions

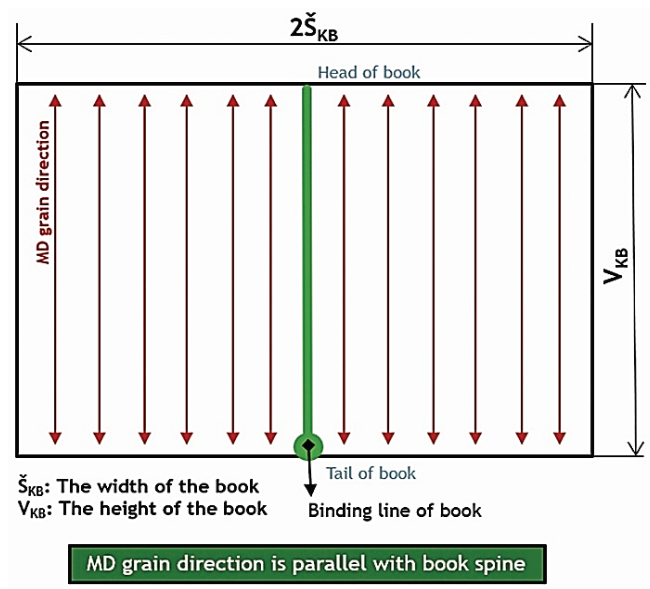

Figure 11 Perfect bound book construction rules

The obtained results of drape factor (*DF*) for 5 various grammages of the same paper grade is presented in Fig. 12. The results were obtained by Jernann`s unique relative scale [10] that presents binding paper stiffness, its capacity to fall into gutter margin of a book spine. The measurements were conducted on the paper sheet B5 format size samples ($_{B5}90^{CP}$, $_{B5}115^{CP}$, $_{B5}135^{CP}$, $_{B5}150^{CP}$and $_{B5}170^{CP}$).

The obtained DF mean results were achieved respectively sample $_{B5}90^{CP}$ (>11.42 to >12.20), followed by $_{B5}115^{CP}$ (>13.39 to >14.17), $_{B5}135^{CP}$ (>14.57 to >16.17), $_{B5}150^{CP}$ (>17.32 to >18.90) and $_{B5}170^{CP}$ (>18.11 to >20.87). Considering the paper various grammages ($90^{CP} < 115^{CP} < 135^{CP} < 150^{CP} < 170^{CP}$) the obtained order of *DF* results were expected because the bending resistance increases together with the paper grammage increase. Moreover, the *DF* results increase approx. 2 points for each paper grammage in the sequence. The obtained CV results confirm the consistency of potential paper energy samples respectively $_{B5}170^{CP}$ (0.034 ≤ 0.10) followed by $_{B5}135^{CP}$ (0.029 ≤ 0.10), $_{B5}90^{CP}$ (0.029 ≤ 0.10), $_{B5}150^{CP}$ (0.026 ≤ 0.10) and $_{B5}115^{CP}$ (0.018 ≤ 0.10) because of tailored paper sheet structure with the higher virgin fiber networking.

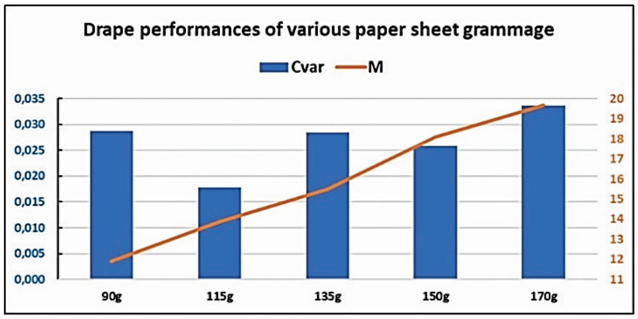

Figure 12 Drape performances of single paper sheet B5 size for different grammages

The higher drape variability was noticed in samples $_{B5}170^{CP}$, $_{B5}90^{CP}$, $_{B5}135^{CP}$ and $_{B5}150^{CP}$, while higher drape stability was shown in the sample $_{B5}115^{CP}$ (Fig. 12). The higher drape stability matches up with paper structural properties. Paper cohesiveness relates to its denser layered structure. This various paper grammages, with their specific structural features, belong to the fine coated paper grade group, which is produced by additional treatment including finishing coatings [16].

4.2 Perfect Bound Book Opening Behaviour

This high-quality wood-free 2-side fine coated paper grade with its various grammages (90^{CP}, 115^{CP}, 135^{CP}, 150^{CP}, 170^{CP}) gave very good book durability with PUR flexible hotmelt. Comprehensive understanding of book design concepts starts with creating optimal book spine mobility in which the appearance of apex arch on the bond line should be minimized. The spine mobility is estimated through visual and tactile experience of end-user (Fig. 12). The readers get the first expression of a book by opening and scrolling it. End-users can handle a book in different ways, which can lead to its worn out appearance. Therefore, it is not enough to choose a suitable paper grade with optimal binding capacity, but designers must choose appropriate paper "toughness" to withstand adverse conditions of book handling. Moreover, preferable paper cohesive features must contribute to creating an apex arch on a book spine. Cohesiveness features come from optimal paper drape capacity, which ensures a balanced shape of a book spine. The formed apex arch on a book spine must provide the ability of the pages to lie one on top of the other without loads.

The highest drape capacity showed sample $_{A5}170^{CP}$, followed by $_{A5}150^{CP}$, $_{B5}150^{CP}$, $_{A5}135^{CP}$ and $_{B5}135^{CP}$. Each of them resists falling naturally onto adjacent pages in a bound book. Moreover, the additional force is necessary for a book to get fully open into the reading position without its self-closing. It is very important to emphasize that getting a full bound book opening is hard to achieve with perfect binding style, especially with A5 format size samples which include higher paper grammages respectively ($170^{CP} > 150^{CP} > 135^{CP}$). In addition, by increasing potential paper energy the book spine mobility is reduced, which immediately leads to forming the higher apex arch. Unfortunately, in such conditions flexible PUR hotmelt cannot neutralize or compensate stress on a book spine.

Figure 13 Perfect bound book appearance depends on a book format size (A5 format, B5 format, square format)

The optimal book spine mobility is shown in the samples respectively $_{A5}115^{CP}$ followed by $_{B5}115^{CP}$, $_{A5}90^{CP}$ and $_{B5}90^{CP}$. From previously mentioned, preferable opening behaviour of bound book is noticed in book format size samples A5 and B5. Moreover, paper grammage reduction leads to a good balanced book spine shape including a minimal apex arch ($_{B5}90^{CP} \geq {}_{A5}90^{CP} > {}_{B5}115^{CP} \geq {}_{A5}115^{CP} > {}_{B5}135^{CP}$). Because of flexible PUR hotmelt, book pages can fall naturally onto adjacent, while a lower potential paper energy contributes to its favourable visual and tactile performances.

On the other hand, the square format size samples ($_{SQ}90^{CP}$, $_{SQ}115^{CP}$, $_{SQ}135^{CP}$, $_{SQ}150^{CP}$, $_{SQ}170^{CP}$) showed preferable opening behaviour, although paper cohesive features had no effect on the apex arch formation. The formed round book spine shape is the result of huge dimensions (310×310 mm) of Perfect bound book. For that reason, the balanced book shape of spine cannot be achieved.

5 CONCLUSIONS

An optimal adhesive bound book performance can be achieved by appropriate prefect binding manufacturing, in which a chosen book engineering concept contributes to its durability and binding efficiency at the same time. Moreover, its functional performances should satisfy end-users' expectations.

In this research, the novel approaches to book designing that contribute to maximum utilization of technological capacities were given. Moreover, they follow perfect (adhesive) binding standardized procedures ISO 16763 within Standards Framework of graphic arts industry ISO/TC 130. Comprehensive binding capacity of standardized paper grades (EN643:2001), including their specific drape features, should help designers in realization of bound book concepts with hotmelts. Moreover, they must be able to cope with technological bindery practices which ultimately lead to perfect (adhesive) binding style efficiency. The binding and drape capacity depends on cohesive attributes of standardized paper grades. Paper compression and extension abilities refer to its bending stiffness. These novel approaches ensure higher-level usability of a book by choosing appropriate drape features, including various grammages of the same paper grade. In addition, this advanced approach leads to satisfactory book spine appearance, in which book pages fall freely to the cover. Because the favourable paper drape features, the created apex arch on book spine ensures a balanced spine shape. Moreover, the flexible PUR hotmelt can compensate more stress on a book spine only if a designer finds out appropriate paper sheet cohesive attributes, which are the best ones in the same paper rank. Fiber resources and other paper ingredients affect its structure formation and cohesiveness. Therefore, the paper sheet cohesive attributes need to provide desirable binding strength quality level and at the same time show preferable performances to bending well, in accordance with standardized guidelines for perfect (adhesive) binding style.

The research proves enhancing performances of bound book with hotmelt in conditions when the layered fiber network structure is denser on the top surface and its central part of standardized paper sheet. Moreover, the cohesive attributes are additionally boosted by paper surface multi-layered coatings which stabilize drape performances and form a balanced book spine shape. In such conditions, the book is able to retain and return in previous position without damage. In addition, the research confirms that a square format gives a favourable book spine appearance regardless of the paper stiffness increase.

Considering the longer bookshelf-life, a designer should steer towards tailoring paper cohesive features in order to optimize the visual-tactile bound book appearance and not only its strength level quality or book durability. Therefore, designers should rely on previous practical knowledge which is connected to current experience and prior comprehensive binding knowledge. Moreover, constructing a great number of bound book prototypes help them to understand paper cohesive features and to copes with problems. The awareness of book designing concepts creates new advanced sustainable approaches and strategies on how to meet the bookbinders' expectations in accordance with technical and technological bindery aspects.

A future perspective in bindery sector should rely on designer superiority in making decisions which are based on background practical experiences (handmaking prototypes) in determining book purpose importance. Moreover, designers should be able to juggle easily with various standardized paper grades and their grammages in accordance with the standardized bindery framework.

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